ISSUE ONE

NewScientist
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THE BIG *QUESTIONS*

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CONSCIOUSNESS

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NewScientist
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Big questions, bold answers

ISSUE ONE
THE BIG QUESTIONS

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ONE of the most profound moments in life is when, as a child, we first utter that small but powerful word, "why?"

This is arguably what defines us a species. We are not so much *Homo sapiens* as *Homo curiosum*. It is not hard to imagine our earliest ancestor looking up at the stars, watching the seasons change, or holding a newborn child and wondering: why?

Our curiosity knows no bounds and it has taken us a long way, from the savannahs of east Africa to world domination and beyond.

Most of this progress has come in the past 300 years thanks to the invention of a systematic way of asking questions and answering them. That method is called science, and it has produced the greatest knowledge bounty ever.

But we still yearn to know why. There is much that we don't understand, and every new discovery opens up new questions.

This first issue of *New Scientist: The Collection* is dedicated to the wonders of human curiosity. A compilation of classic articles published in *New Scientist*, it explores the profound questions we ask of ourselves and the universe around us.

In Chapter 1 we ask perhaps the most fundamental question of all: what is reality? Looking at the world around you, the answer might seem obvious – until you dig deep, when reality reveals itself to be a slippery customer.

Chapter 2 takes a more personal and reflective turn, asking what the discoveries of modern science mean for our own existence, from the search for aliens to the bizarre possibility that you are a hologram.

Chapter 3 casts a new perspective on one of the oldest answers in the book: that everything can be explained by the existence of an all-powerful supernatural being. We are now largely dissatisfied with that answer, but God continues to fascinate.

Chapter 4 returns to personal experience, specifically the granite-hard problem of the nature of consciousness, how something so incredible can be produced by 1500 grams or so of brain tissue, and why you cannot be sure that everybody else is not a zombie.

Chapter 5 is dedicated to a phenomenon that, as far as we know, is confined to a tiny corner of the universe: life itself. We know it got going on Earth almost as soon as the planet was habitable – but why did it take so long to give rise to complex creatures? And does it have a future?

In Chapter 6, we probe one of the universe's most puzzling dimensions: time. The everyday ticking of a clock might seem the most natural thing in the world, but it masks a very peculiar phenomenon.

Chapter 7 focuses inwards again, dismantling the entity we call the self, which seems so solid and enduring to each of us and yet doesn't appear to actually exist.

In Chapter 8 we explore the familiar yet strange world of sleep and dreaming – a place we visit every night but which nonetheless remains eerie and elusive.

Finally, Chapter 9 faces up to the end. There is perhaps no older question about human life than why it must one day cease. But viewed the right way, death can both fascinate and inspire. ■

Graham Lawton, Editor

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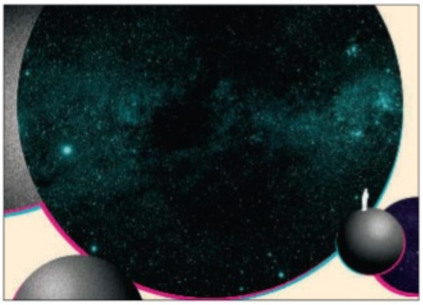

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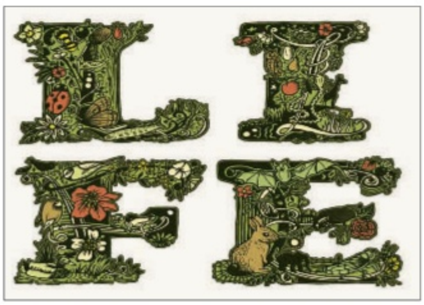

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REALITY

WHEN you woke up this morning, you found the world largely as you left it. You were still you; the room in which you awoke was the same one you went to sleep in. The outside world had not been rearranged. History was unchanged and the future remained unknowable. In other words, you woke up to reality. But what is reality? It's surprisingly hard to say. Even defining it is difficult. Whatever reality is, it isn't what it seems...

DEFINING REALITY

By Jan Westerhoff

WHAT DO we actually mean by reality? A straightforward answer is that it means everything that appears to our five senses – everything that we can see, smell, touch and so forth. Yet this answer ignores such problematic entities as electrons, the recession and the number 5, which we cannot sense but which are very real. It also ignores phantom limbs and illusory smells. Both can appear vividly real, but we would like to say that these are not part of reality.

We could tweak the definition by equating reality with what appears to a sufficiently large group of people, thereby ruling out subjective hallucinations. Unfortunately there are also hallucinations experienced by large groups, such as a mass delusion known as koro, mainly observed in South-East Asia, which involves the belief that one's genitals are shrinking back into one's body. Just because sufficiently many people believe in something does not make it real.

Another possible mark of reality we could focus on is the resistance it puts up: as the science fiction writer Philip K. Dick put it, reality is that which, if you stop believing in it, does not go away. Things we just make up yield to our wishes and desires, but reality is stubborn. Just because I believe there is a jam doughnut in front of me doesn't mean there really is one. But again, this definition is problematic. Things that we do not want to regard as real can be stubborn too, as anyone who has ever been trapped in a nightmare knows. And some things that are real, such as stock markets, are not covered by this definition because if everyone stopped believing in them, they would cease to exist.

There are two definitions of reality that are much more successful. The first equates reality with a world without us, a world untouched by human desires and intentions. By this definition, a lot of things we usually regard as real – languages, wars, the financial crisis – are nothing of the sort. Still, it is the most solid one so far because it removes human subjectivity from the picture.

The second equates reality with the most fundamental things that everything else depends on. In the material world, molecules depend on their constituent atoms, atoms on electrons and a nucleus, which in turn depends on protons and neutrons, and so on. In this hierarchy, every level depends on the one below it, so we might define reality as made up of whatever entities stand at the bottom of the chain of dependence, and thus depend on nothing else.

This definition is even more restrictive than "the world without us" since things like Mount Everest would not count as part of reality; reality is confined to the unknown foundation on which the entire world depends. Even so, when we investigate whether something is real or not, these final two definitions are what we should have in mind. ■

THE BEDROCK OF IT ALL

Our basic understanding of matter and energy is impressive, but falls well short of a complete theory of reality, says **Valerie Jamieson**

IS ANYTHING real? The question seems to invite only one answer: of course it is. If in doubt, try kicking a rock.

Leaving aside the question of whether your senses can be trusted, what are you actually kicking? When it boils down to it, not a lot. Science needs remarkably few ingredients to account for a rock: a handful of different particles, the forces that govern their interactions, plus some rules laid down by quantum mechanics.

This seems like a solid take on reality, but it quickly starts to feel insubstantial. If you take a rock apart, you'll find that its basic constituent is atoms – perhaps 1000 trillion trillion of them, depending on the rock's size. Atoms, of course, are composed of smaller subatomic particles, namely protons and neutrons – themselves built of quarks – and electrons. Otherwise, though, atoms (and hence rocks) are mostly empty space. If an atom were scaled up so that its nucleus was the size of the Earth, the distance to its closest electrons would be 2.5 times the distance between the Earth and the sun. In between is nothing at all. If so much of reality is built on emptiness, then what gives rocks and other objects their form and bulk?

Physics has no problem answering this question: electrons. Quantum rules dictate that no two electrons can occupy the same quantum state. The upshot of this is that, no matter how hard you try, you cannot cram two atoms together into the same space. "Electrons do all the work when it comes to the structure of matter we see all around us," says physicist Sean Carroll at the California Institute of Technology in Pasadena.

That's not to say the nucleus is redundant. Most of the mass of an atom comes from protons and neutrons and the force binding them together, which is carried by particles called gluons.

And that, essentially, is that. Electrons, quarks (mostly of the up and down variety) and gluons account for most of the ordinary stuff around us.

But not all. Other basic constituents of reality exist too – 17 in total, which together comprise the standard model of particle physics (see illustration, below). The model also accounts for the mirror world of antimatter with a complementary set of antiparticles.

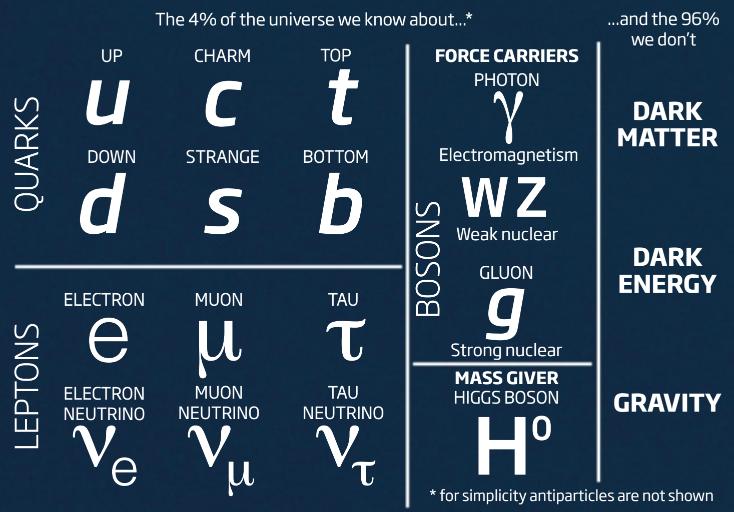
Some pieces of the standard model are commonplace, such as photons of light and the various neutrinos streaming through us from the sun and other sources. Others, though, do not seem to be part of everyday reality, including the top and bottom quarks and the heavy, electron-like tau particle. "On the face of it, they don't play a role," says Paul Davies of Arizona State University in Tempe. "Deep down, though, they may all link up."

That's because the standard model is more than a roll call of particles. Its foundations lie in symmetry and group theory, one example of the mysterious connections between reality and mathematics (see page 10).

The standard model is arguably even stranger for what it doesn't include. It has nothing to say about the invisible dark matter than seems to make up most of the matter in the universe. Nor does it account for dark energy. These are serious omissions when you consider that dark matter and dark energy together comprise about 96 per cent of the universe. It is also totally unclear how the standard model relates to phenomena that seem to be real, such as time and gravity.

So the standard model is at best a fuzzy approximation, encompassing some, but not all, of what seems to comprise physical reality, plus bits and pieces that do not. Most physicists would agree that the standard model is in serious need of an overhaul. It may be the best model we have of reality, but it is far from the whole story. ■

The basic ingredients of reality



IS MATTER REAL?

It's relatively easy to demonstrate what physical reality isn't. Understanding what it *is* is much harder, says **Jan Westerhoff**

NOTHING seems more real than the world of everyday objects, but things are not as they seem. A set of relatively simple experiments reveals enormous holes in our intuitive understanding of physical reality. Trying to explain what goes on leads to some very peculiar and often highly surprising theories of the world around us.

Here is a simple example. Take an ordinary desk lamp, a few pieces of cardboard with holes of decreasing sizes, and some sort of projection screen such as a white wall. If you put a piece of cardboard between the lamp and the wall, you will see a bright patch where the light passes through the hole in the cardboard. If you now replace the cardboard with pieces containing smaller and smaller holes, the patch too will diminish in size. Once we get below a certain size, however, the pattern on the wall changes from a small dot to a series of concentric dark and light rings, rather like an archery target. This is the "Airy pattern" – a characteristic sign of a wave being forced through a hole (see above left).

In itself, this is not very surprising. After all, we know that light is a wave, so it should display wave-like behaviour.

But now consider what happens if we change the set-up of the experiment a bit. Instead of a lamp, we use a device

"IF IN DOUBT THAT MATTER IS REAL, TRY KICKING A ROCK"

CHRISTOPHE AGOU

IS EVERYTHING MADE OF NUMBERS?

The fact that the natural world can be described so precisely by mathematics is telling us something profound, says **Amanda Gefter**

WHEN Albert Einstein finally completed his general theory of relativity in 1916, he looked down at the equations and discovered an unexpected message: the universe is expanding.

Einstein didn't believe the physical universe could shrink or grow, so he ignored what the equations were telling him. Thirteen years later, Edwin Hubble found clear evidence of the universe's expansion. Einstein had missed the opportunity to make the most dramatic scientific prediction in history.

How did Einstein's equations "know" that the universe was expanding when he did not? If mathematics is nothing more than a language we use to describe the world, an invention of the human brain, how can it possibly churn out anything beyond what we put in? "It is difficult to avoid the impression that a miracle confronts us here," wrote physicist Eugene Wigner in his classic 1960 paper "The unreasonable effectiveness of mathematics in the natural sciences".

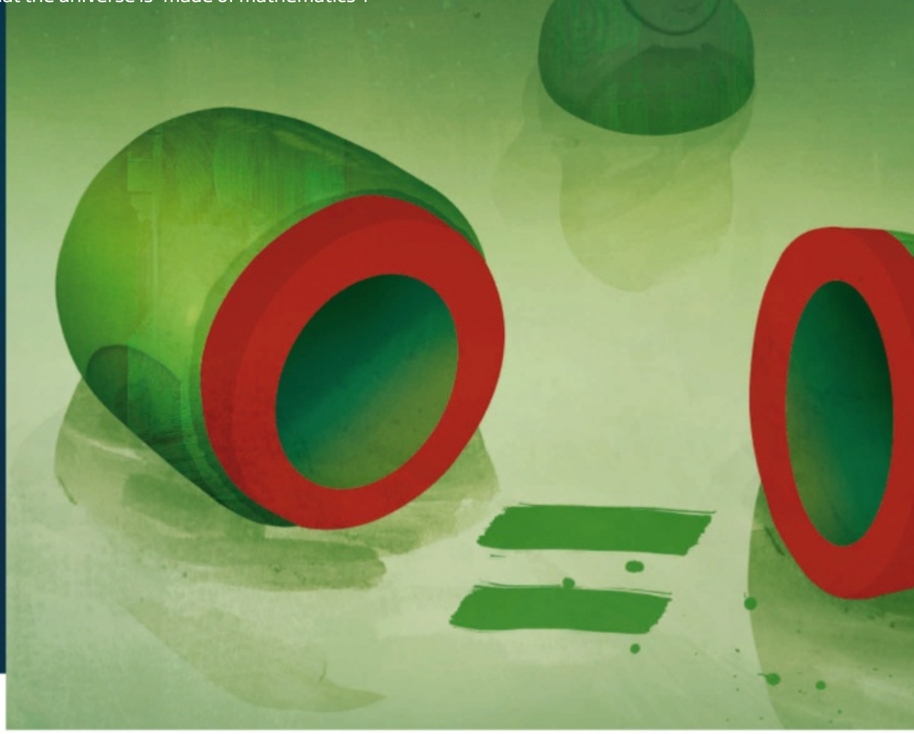
The prescience of mathematics seems no less miraculous today. At the Large Hadron Collider at CERN, near Geneva, Switzerland, physicists recently confirmed the existence of a particle that was arguably discovered 48 years ago lurking in the equations of particle physics.

How is it possible that mathematics "knows" about Higgs particles or any other feature of physical reality? "Maybe it's because math *is* reality," says physicist Brian Greene of Columbia University in New York. Perhaps if we dig deep enough, we would find that physical objects like tables and chairs are ultimately not made of particles or strings, but of numbers.

"These are very difficult issues," says philosopher of science James Ladyman of the University of Bristol, UK, "but it might be less misleading to say that the universe is made of maths than to say it is made of matter."

Difficult indeed. What does it mean to say that the universe is "made of mathematics"? An obvious starting point is to ask what mathematics is made of. The late physicist John Wheeler said that the "basis of all mathematics is 0 = 0". All mathematical structures can be derived from something called "the empty set", the set that contains no elements. Say this set corresponds to zero; you can then define the number 1 as the set that contains only the empty set, 2 as the set containing the sets corresponding to 0 and 1, and so on. Keep nesting the nothingness like invisible Russian dolls and eventually all of mathematics appears. Mathematician Ian Stewart of the University of Warwick, UK, calls this "the dreadful secret of mathematics: it's all based on nothing". Reality may come down to mathematics, but mathematics comes down to nothing at all.

That may be the ultimate clue to existence – after all, a universe made of nothing doesn't require an explanation. Indeed, mathematical structures don't seem to require a physical origin at all. "A dodecahedron was never created," says



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Max Tegmark of the Massachusetts Institute of Technology. "To be created, something first has to not exist in space or time and then exist." A dodecahedron doesn't exist in space or time at all, he says – it exists independently of them. "Space and time themselves are contained within larger mathematical structures," he adds. These structures just exist; they can't be created or destroyed.

That raises a big question: why is the universe only made of some of the available mathematics? "There's a lot of math out there," Greene says. "Today only a tiny sliver of it has a realisation in the physical world. Pull any math book off the shelf and most of the equations in it don't correspond to any physical object or physical process."

It is true that seemingly arcane and unphysical mathematics does, sometimes, turn out to correspond to the real world. Imaginary numbers, for instance, were once considered totally deserving of their name, but are now used to describe the behaviour of elementary particles; non-Euclidean geometry eventually showed up as gravity. Even so, these phenomena represent a tiny slice of all the mathematics out there.

Not so fast, says Tegmark. "I believe that physical existence and mathematical existence are the same, so any structure that exists mathematically is also real," he says.

So what about the mathematics our universe doesn't use? "Other mathematical structures correspond to other universes," Tegmark says. He calls this the "level 4 multiverse", and it is far stranger than the multiverses that cosmologists often discuss. Their common-or-garden multiverses are governed by the same basic mathematical rules as our universe, but Tegmark's level 4 multiverse operates with completely different mathematics.

All of this sounds bizarre, but the hypothesis that physical reality is fundamentally mathematical has passed every test. "If physics hits a roadblock at which point it turns out that it's impossible to proceed, we might find that nature can't be captured mathematically," Tegmark says. "But it's really remarkable that that hasn't happened. Galileo said that the book of nature was written in the language of mathematics – and that was 400 years ago."

If reality isn't, at bottom, mathematics, what is it? "Maybe someday we'll encounter an alien civilisation and we'll show them what we've discovered about the universe," Greene says. "They'll say, 'Ah, math. We tried that. It only takes you so far. Here's the real thing.' What would that be? It's hard to imagine. Our understanding of fundamental reality is at an early stage." ■

"PHYSICAL EXISTENCE AND MATHEMATICAL EXISTENCE ARE ONE AND THE SAME"

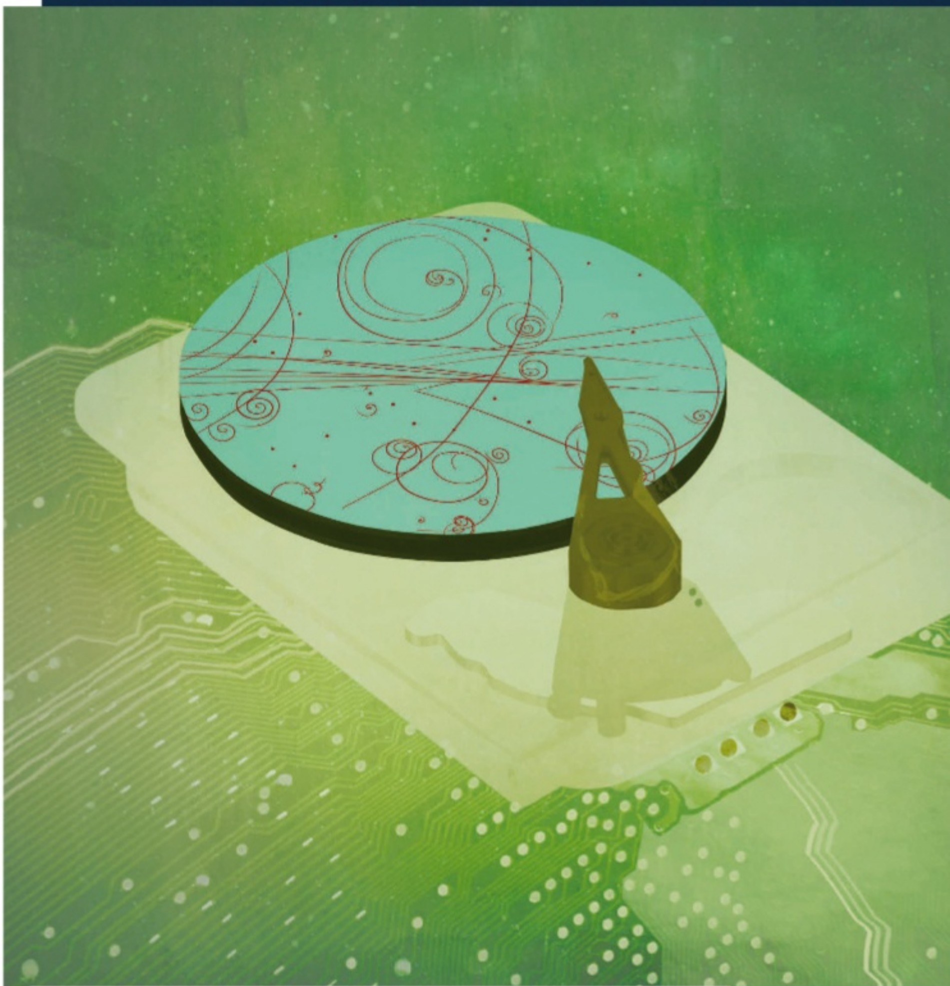
that shoots out electrons, like that found in old-fashioned TV sets; instead of the wall, we use a plate of glass coated with a phosphor that lights up when an electron strikes it. We can therefore use this screen to track the places where the electrons hit. The results are similar: with sufficiently small holes we get an Airy pattern.

This now seems peculiar: electrons are particles located at precise points and cannot be split. Yet they are behaving like waves that can smear out across space, are divisible, and merge into one another when they meet.

Perhaps it is not that strange after all. Water consists of molecules, yet it behaves like a wave. The Airy pattern may just emerge when enough particles come together, whether they are water molecules or electrons.

A simple variant of the experiments shows, however, that this cannot be right. Suppose we reduce the output of the electron gun to one particle each minute. The Airy pattern is gone, and all we see is a small flash every minute. Let's leave this set-up to run for a while, recording each small flash as it occurs. Afterwards, we map the locations of all the thousands of flashes.

Surprisingly, we do not end up with a random arrangement of dots, but with the Airy pattern again. This result is extremely strange. No individual electron can know where all the earlier and later electrons are going to hit, so they cannot communicate with each



DARREN HOPES

other to create the bullseye pattern. Rather, each electron must have travelled like a wave through the hole to produce the characteristic pattern, then changed back into a particle to produce the point on the screen. This, of course, is the famous wave-particle duality of quantum mechanics.

This strange behaviour is shared by any sufficiently small piece of matter, including electrons, neutrons, photons and other elementary particles, but not just by these. Similar effects have been observed for objects that are large enough in principle to be seen under a microscope, such as buckyballs.

In order to explain the peculiar behaviour of such objects, physicists associate a wave function with each of them. Despite the fact that these waves have the usual properties of more familiar waves such as sound or water waves, including amplitude (how far up or down it deviates from the rest state), phase (at what point in a cycle the wave is), and interference (so that "up" and "down" phases of waves meeting each other cancel out), what they are waves *in* is not at all transparent. Einstein aptly spoke of a "phantom field" as their medium.

For a wave in an ordinary medium such as water, we can calculate its energy at any one point by taking the square of its amplitude. Wave functions, however, carry no energy. Instead, the square of their amplitude at any given point gives us the probability of observing the particle if a detector such as the phosphor-coated screen is placed there.

Clearly, the point where an object switches from being a probability wave, with its potential existence smeared out across space, and becomes an actual, spatially localised object is crucially important to understanding whether matter is real. What exactly happens when the wave function collapses – when among the countless possibilities where the particle could be at any moment, one is chosen, while all the others are rejected?

First of all, we have to ask ourselves when this choice is made. In the example described above, it seems to happen just before the flash on the phosphor screen. At this moment, a measurement of the electron's position was made by a piece of phosphor glowing as the particle struck it, so there must have been an electron there, and not just a probability wave.

But assume we cannot be in the lab to observe the experiment, so we point a camera at the phosphor screen and have the result sent via a satellite link to a computer on our desktop. In this case, the flash of light emitted from the phosphor screen has to travel to the camera recording it, and the process is

IF INFORMATION... THEN UNIVERSE

Find the idea of a universe made of mathematics hard to swallow? Then try this on for size, says **Michael Brooks**

WHATEVER kind of reality you think you're living in, you're probably wrong. The universe is a computer, and everything that goes on in it can be explained in terms of information processing.

The connection between reality and computing may not be immediately obvious, but strip away the layers and that is exactly what some researchers think we find. We think of the world as made up of particles held together by forces, for instance, but quantum theory tells us that these are just a mess of fields we can only properly describe by invoking the mathematics of quantum physics.

That's where the computer comes in, at least if you think of it in conceptual terms as something that processes information rather than as a boxy machine on your desk. "Quantum physics is almost phrased in terms of information processing," says Vlatko Vedral of the University of Oxford. "It's suggestive that you will find information processing at the root of everything."

Information certainly has a special place in quantum theory. The famous uncertainty principle – which states that you can't simultaneously know the momentum and position of a particle – comes down to information. As does entanglement, where quantum objects share properties and exchange information irrespective of the physical distance between them.

In fact, every process in the universe can be reduced to interactions between particles that produce binary answers: yes or no, here or there, up or down. That means nature, at its most fundamental level, is simply the flipping of binary digits or bits, just like a computer. The result of the myriad bit flips is manifest in what we perceive as the ongoing arrangement, rearrangement and interaction of atoms – in other words, reality.

According to Ed Fredkin of Carnegie Mellon University and the Massachusetts Institute of Technology, if we could dig into this process we would find that the universe follows just one law, a single information-processing rule that is all you need to build a cosmos. In Fredkin's view, this would be some form of "if – then" procedure; the kind of rule used in traditional computing to manipulate the bits held by transistors on a chip and operate the logic gates, but this time applied to the bits of the universe.

Vedral and others think it's a little more complex than that. Because we can reduce everything in the universe to entities that follow the laws of quantum physics, the universe must be a quantum computer rather than the classical type we are familiar with.

One of the attractions of this idea is that it can supply an answer to the question "why is there something rather than nothing?". The randomness inherent in quantum mechanics means that quantum information – and by extension, a universe – can spontaneously come into being, Vedral says.

For all these theoretical ideas, proving that the universe is a quantum computer is a difficult task. Even so, there is one observation that supports the idea that the universe is fundamentally composed of information. In 2008, the GEO600 gravitational wave detector in Hannover, Germany, picked up an anomalous signal suggesting that space-time is pixelated. This is exactly what would be expected in a "holographic" universe, where 3D reality is actually a projection of information encoded on the two-dimensional surface of the boundary of the universe.

This bizarre idea arose from an argument over black holes. One of the fundamental tenets of physics is that information cannot be destroyed, but a black hole appears to violate this by swallowing things that contain information, then gradually evaporating away. What happens to that information was the subject of a long debate between Stephen Hawking and several of his peers. In the end, Hawking lost the debate, conceding that the information is imprinted on the event horizon that defines the black hole's boundary and escapes as the black hole evaporates. This led theoretical physicists Leonard Susskind and Gerard 't Hooft to propose that the entire universe could also hold information at its boundary – with the consequence that our reality could be the projection of that information into the space within the boundary (see page 23). If this conjecture is true, reality is like the image of Princess Leia projected by R2D2 in *Star Wars*: a hologram. ■

"THE UNIVERSE MUST BE A QUANTUM COMPUTER"

repeated: like the electrons, light also travels as a wave and arrives as a particle. What reason is there to believe that the switch from probability wave to particle actually occurred on the phosphor screen, and not in the camera?

At first, it seemed as if the phosphor screen was the measuring instrument, and the electron was the thing being measured. But now the measuring device is the camera and the phosphor screen is part of what is measured. Given that any physical object transmitting the measurement we can add on to this sequence – the camera, the computer, our eyes, our brain – is made up of particles with the same properties as the electron, how can we determine any particular step at which to place the cut between what is measured and what is doing the measuring?

This ever-expanding chain is called the von Neumann chain, after the physicist and mathematician John von Neumann. One of his Princeton University colleagues, Eugene Wigner, made a suggestion as to where to make the cut. As we follow the von Neumann chain upwards, the first entity we encounter that is not made up in any straightforward fashion out of pieces of matter is the consciousness of the observer. We might therefore want to say that when consciousness enters the picture, the wave function collapses and the probability wave turns into a particle.

The idea that consciousness brings everyday reality into existence is, of course, deeply strange; perhaps it is little wonder that it is a minority viewpoint.

There is another way of interpreting the measurement problem that does not involve consciousness – though it has peculiar ramifications of its own. But for now let's explore Wigner's idea in more depth.

If a conscious observer does not collapse the wave function, curious consequences follow. As more and more objects get sucked into the vortex of von Neumann's chain by changing from being a measuring instrument to being part of what is measured, the "spread-out" structure of the probability wave becomes a property of these objects too. The "superposed" nature of the electron – its ability to be at various places at once – now also affects the measuring instruments.

It has been verified experimentally that not just the unobservably small, but objects large enough to be seen under a microscope, such as a 60-micrometre-long metal strip, can exhibit such superposition behaviour. Of course, we can't look through a microscope and see the metal strip being at two places at once, as this would immediately collapse the wave function. Yet it is clear that the indeterminacy we found at the atomic level can spread to the macro level.

Yet if we accept that the wave function must collapse as soon as consciousness enters the measurement, the consequences are even more curious. If we decide to break off the chain at this point, it follows that, according to one of our definitions of reality, matter cannot be regarded as real. If consciousness is required to turn ghostly probability waves into things that are more or less like the objects we meet in everyday life, how can we say that matter is what would be there anyway, whether or not human minds were around?

But perhaps this is a bit too hasty. Even if we agree with the idea that consciousness is required to break the chain, all that follows is that the dynamic attributes of matter such as position, momentum and spin orientation are mind-dependent. It does not follow that its static attributes, including mass and charge, are dependent on in this. The static attributes are there whether we look or not.

Nevertheless, we have to ask ourselves whether redefining matter as "a set of static attributes" preserves enough of its content to allow us to regard matter as real. In a world without minds, there would still be attributes such as mass and charge, but things would not be at any particular location or travel in any particular direction. Such a world has virtually nothing in common with the world as it appears to us. Werner Heisenberg observed that: "the ontology of materialism rested upon the illusion that the kind of existence, the direct 'actuality' of the world around us, can be extrapolated into the atomic range. This extrapolation, however, is impossible... Atoms are not things."

It seems that the best we are going to get at this point is the claim that some things are there independent of whether we, as human observers, are there, even though they might have very little to do with our ordinary understanding of matter.

Does our understanding of the reality of matter change if we choose the other strong definition of reality – not by what is there anyway, but by what provides the foundation for everything else?

In order to answer this question, we have to look at the key scientific notion of a reductive explanation. Much of the power of scientific theories derives from the insight that we can use a theory that applies to a certain set of objects to explain the behaviour of a quite different set of objects. We therefore don't need a separate set of laws and principles to explain the second set.

A good example is the way in which theories from physics and chemistry, dealing with inanimate matter, can be used to explain biological processes. There is no need to postulate a special physics or a special chemistry to explain an organism's metabolism, how it procreates, how its genetic information is passed on, or how it ages and dies. The behaviour of the cells that make up the organism can be accounted for in terms of the nucleus, mitochondria and other subcellular entities, which can in turn

DOES CONSCIOUSNESS CREATE REALITY?

If a tree falls in the forest and there's nobody there, maybe there isn't even a forest, says Michael Brooks

ERICH HARTMANN/MAGNUM

DESCARTES might have been on to something with "I think therefore I am", but surely "I think therefore you are" is going a bit far? Not for some of the brightest minds of 20th-century physics as they wrestled mightily with the strange implications of the quantum world.

According to prevailing wisdom, a quantum particle such as an electron or photon can only be properly described as a mathematical entity known as a wave function. Wave functions can exist as "superpositions" of many states at once. A photon, for instance, can circulate in two different directions around an optical fibre; or an electron can simultaneously spin clockwise and anticlockwise or be in two positions at once.

When any attempt is made to observe these simultaneous existences, however, something odd happens: we see only one. How do many possibilities become one physical reality?

This is the central question in quantum mechanics, and has spawned a plethora of proposals, or interpretations. The most popular is the Copenhagen interpretation, which says nothing is real until it is observed, or measured. Observing a wave function causes the superposition to collapse.

However, Copenhagen says nothing about what exactly constitutes an observation. John von Neumann broke this silence and suggested that observation is the action of a conscious mind. It's an idea also put forward by Max Planck, the founder of quantum theory, who said in 1931, "I regard consciousness as fundamental. I regard matter as derivative from consciousness."

That argument relies on the view that there is something special about consciousness, especially human consciousness. Von Neumann argued that everything in the universe that is subject to the laws of quantum physics creates one vast quantum superposition. But the conscious mind is somehow different. It is thus able to select out one of the quantum possibilities on offer, making it real – to that mind, at least.

Henry Stapp of the Lawrence Berkeley National Laboratory in California is one of the few physicists that still subscribe to this notion: we are "participating observers" whose minds cause the collapse of superpositions, he says. Before human consciousness appeared, there existed a multiverse of potential universes, Stapp says. The emergence of a conscious mind in one of these potential universes, ours, gives it a special status: reality.

There are many objectors. One problem is that many of the phenomena involved are poorly understood. "There's a big question in philosophy about whether consciousness actually exists," says Matthew Donald, a philosopher of physics at the University of Cambridge. "When you add on quantum mechanics it all gets a bit confused."

Donald prefers an interpretation that is arguably even more bizarre: "many minds". This idea – related to the "many worlds" interpretation of quantum theory, which has each outcome of a quantum decision happen in a different universe – argues that an individual observing a quantum system sees all the many states, but each in a different mind. These minds all arise from the physical substance of the brain, and share a past and a future, but cannot communicate with each other about the present.

Though it sounds hard to swallow, this and other approaches to understanding the role of the mind in our perception of reality are all worthy of attention, Donald reckons. "I take them very seriously," he says. ■

be explained in terms of chemical reactions based on the behaviour of molecules and the atoms that compose them. For this reason, explanations of biological processes can be said to be reducible to chemical and ultimately to physical ones.

If we pursue a reductive explanation for the phenomena around us, a first step is to reduce statements about the medium-sized goods that surround us – bricks, brains, bees, bills and bacteria – to statements about fundamental material objects, such as molecules. We then realise everything about these things can be explained in terms of their constituents, namely their atoms. Atoms, of course, have parts as well, and we are now well on our way through the realm of ever smaller subatomic particles, perhaps (if string theory is correct) all the way down to vibrating strings of pure energy. So far we have not reached the most fundamental objects. In fact, there is not even an agreement that there are any such objects.

Yet this is no reason to stop our reductionist explanation here, since we can always understand the most basic physical objects in terms of where they are in space and time. Instead of talking about a certain particle that exists at such-and-such a place for such-and-such a period of time, we can simply reduce this to talk about a certain region in space that is occupied between two different times.

We can go even more fundamental. If we take an arbitrary fixed point in space, and a stable unit of spatial distance, we can specify any other point in space by three coordinates. These simply tell us to go so many units up or down, so many units left or right, and so many units back or forth. We can do the same with points in time. We now have

TOSHIO KISHIYAMA

"IT IS DIFFICULT TO REFUTE THE IDEA THAT CONSCIOUSNESS IS ALL THERE IS"

a way of expressing points in space-time as sets of four numbers, x, y, z and t, where x, y, and z represent the three spatial dimensions and t the time dimension. In this way, reality can be boiled down to numbers.

And this opens the door to something yet more fundamental. Mathematicians have found a way of reducing numbers to something even more basic: sets. To do this, they replace the number 0 with the empty set, the number 1 with the set that contains just the empty set, and so on (see page 10). All the properties of numbers also hold for all these ersatz numbers made from sets. It seems as if we have now reduced all of the material world around us to an array of sets.

For this reason, it is important to know what these mathematical objects called sets really are. There are two views of mathematical objects that are important in this context. First, there is the view of them as "Platonic" objects. This means that mathematical objects are unlike all other objects we encounter. They are not made of matter, they do not exist in space or time, do not change, cannot be created or destroyed, and could not have failed to exist. According to the Platonic understanding, mathematical objects exist in a "third realm", distinct from the world of matter, on the one hand, and the world of mental entities, such as perceptions, thoughts and feelings, on the other.

Second, we can understand mathematical objects as fundamentally mental in nature. They are of the same kind as the other things that pass through our mind: thoughts and plans, concepts and ideas. They are not wholly subjective; other people can have the

HOW DO WE KNOW?

Of course, reality could all be an illusion, but proving it one way or the other is surprisingly difficult, says **Mike Holderness**

PHILOSOPHERS are not being rude when they describe the approach most of us take as naive realism. After all, when they cross the street on the way to work, they tend to accept implicitly – as we all do – that there is an external reality that exists independently of our observations of it. But at work, they have to ask: if there is, how can we know?

In other words, the question "what exists?" reduces, for what in philosophy passes for practical purposes, to questions such as "what do we mean by 'know'?"

Plato had a go at it 2400 years ago, defining "knowledge" as "justified true belief". But testing the justification or the truth of beliefs traces back to our perceptions, and we know these can deceive us.

Two millennia later, René Descartes decided to work out what he was sure he knew. Legend has it that he climbed into a large stove to do so in warmth and solitude. He emerged declaring that the only thing he knew was that there was something that was doubting everything.

The logical conclusion of Descartes's doubt is solipsism, the conviction that one's own consciousness is all there is. It's an idea that is difficult to refute.

Samuel Johnson's notoriously bluff riposte to the questioning of the reality of objects – "I refute it thus!", kicking a stone – holds no philosophical water. As Descartes pointed out a century earlier, it is impossible to know we are not dreaming.

Nor has anyone had much luck making sense of dualism – the idea that mind and matter are distinct. One response is that there is only matter, making the mind an illusion that arises from neurons doing their thing. The opposite position is "panpsychism", which attributes mental properties to all matter. As the astrophysicist Arthur Eddington expressed it in 1928: "the stuff of the world is mind-stuff... not altogether foreign to the feelings in our consciousness".

Quite separately, rigorous logicians such as Harvard's Willard Van Orman Quine abandoned the search for a foundation of reality and took "coherentist" positions. Let go of the notion of a pyramid of knowledge, they argued: think instead of a raft built out of our beliefs, a seaweedy web of statements about perceptions and statements about statements, not "grounded" in anything but hanging together and solid enough to set sail upon. Or even, possibly, to *be* a universe.

This idea is circular, and it's cheating, say critics of a more foundationist bent. It leads back to the suspicion that there actually is no reality independent of our observations. But if there is – how can we know? ■

very same mathematical object in their minds as we have in ours, so that when we both talk about the Pythagorean theorem, we are talking about the same thing. Still, they do not exist except in the minds in which they occur.

Either of these understandings leads to a curious result. If the bottom level of the world consists of sets, and if sets are not material but are instead some Platonic entities, material objects have completely disappeared from view and cannot be real in the sense of constituting a fundamental basis of all existence. If we follow scientific reductionism all the way down, we end up with stuff that certainly does not look like tiny pebbles or billiard balls, not even like strings vibrating in a multidimensional space, but more like what pure mathematics deals with.

Of course, the Platonistic view of mathematical objects is hardly uncontroversial, and many people find it hard to get any clear idea of how objects could exist outside of space and time. But if we take mathematical objects to be mental in nature, we end up with an even stranger scenario.

The scientific reductionist sets out to reduce the human mind to the activity of the brain, the brain to an assembly of interacting cells, the cells to molecules, the molecules to atoms, the atoms to subatomic particles, the subatomic particles to collections of space-time points, the collections of space-time points to sets of numbers, and the sets of numbers to pure sets. But at the very end of this reduction, we now seem to loop right back to where we came from: to the mental entities.

We encounter a similar curious loop in the most influential way of understanding quantum mechanics, the Copenhagen interpretation. Unlike Wigner's consciousness-based interpretation, this does not assume the wave function collapses when a conscious mind observes the outcome of some experiment. Instead, it happens when the system to be measured (the electron) interacts with the measuring device (the phosphor screen). For this reason, it has to be assumed that the phosphor screen will not itself exhibit the peculiar quantum behaviour shown by the electron.

In the Copenhagen interpretation, then, things and processes describable in terms of familiar classical concepts are the foundation of any physical interpretation. And this is where the circularity comes in. We analyse the everyday world of medium-sized material things in terms of smaller and smaller constituents until we deal with parts that are so small that quantum effects become relevant for describing them. But when it comes to spelling out what is really going on when a wave function collapses into an electron hitting a phosphor screen, we don't ground our explanation in some yet more minute micro-level structures; we ground it in terms of readings made by non-quantum material things.

What this means is that instead of going further down, we instead jump right back up to the level of concrete phenomena of sensory perception, namely measuring devices such as phosphor screens and cameras. Once more, we are in a situation where we cannot say that the world of quantum objects is fundamental. Nor can we say that the world of measuring devices is fundamental since these devices are themselves nothing but large conglomerations of quantum objects.

We therefore have a circle of things depending on each other, even though, unlike in the previous case, mental objects are no longer part of this circle. As a result, neither the phosphor screen nor the minute electron can be regarded as real in any fundamental sense, since neither constitutes a class of objects that everything depends on. What we thought we should take to be the most fundamental turns out to involve essentially what we regarded as the least fundamental.

In our search for foundations, we have gone round in a circle, from the mind, via various components of matter, back to the mind – or, in the case of the Copenhagen interpretation, from the macroscopic to the microscopic, and then back to the macroscopic. But this just means that nothing is fundamental, in the same way there is no first or last stop on London Underground's Circle Line. The moral to draw from the reductionist scenario seems to be that either what is fundamental is not material, or that nothing at all is fundamental. ■

"MATERIAL OBJECTS DISAPPEAR FROM VIEW AND CANNOT BE REAL"

CHAPTER TWO

EXISTENCE

It's lucky you're here

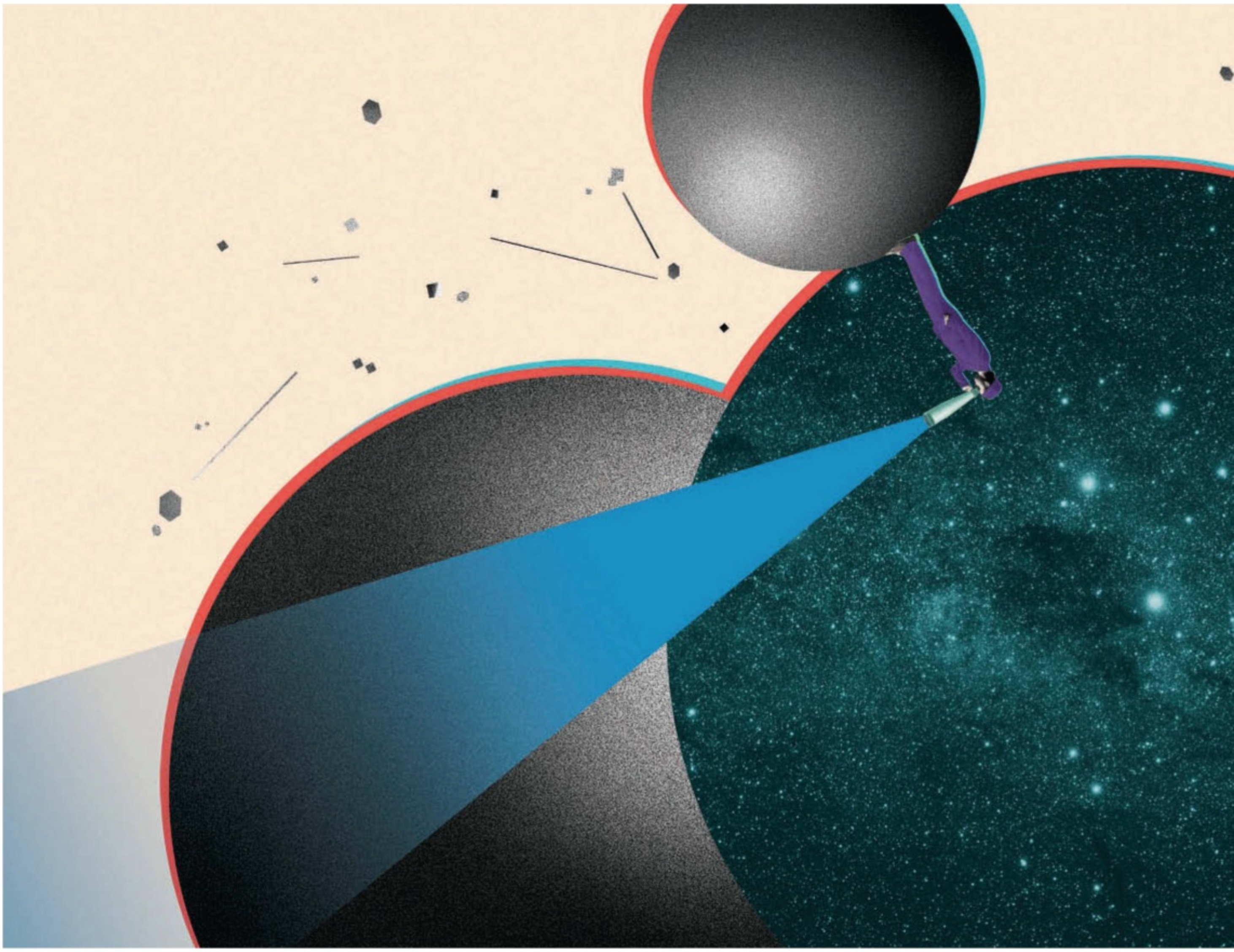
13.7 billion years ago, the universe was born in a cosmic fireball. Roughly 10 billion years later, the planet we call Earth gave birth to life, which eventually led to you. The probability of that sequence of events is absolutely minuscule, and yet it still happened.

Take a step back from the unlikeliness of your own personal existence and things get even more mind-boggling. Why does the universe exist at all? Why is it fine-tuned to human life? Why does it seem to be telling us that there are other universes out there, even other yous?

Confronting these mysteries of existence can lead to bizarre conclusions, from the possibility that the universe is a hologram to the near-certainty that you are a zombie. Enjoy the ride.

JIRAYU KOO/AGENCYRUSH.COM

JIRAYU KOO/AGENCYRUSH.COM



Why is there something rather than nothing?

AS DOUGLAS ADAMS once wrote: "The universe is big. Really big." And yet if our theory of the big bang is right, the universe was once a lot smaller. Indeed, at one point it was non-existent. Around 13.7 billion years ago time and space spontaneously sprang from the void. How did that happen?

Or to put it another way: why does anything exist at all? It's a big question, perhaps the biggest. The idea that the universe simply appeared out of nothing is difficult enough; trying to conceive of nothingness is perhaps even harder.

It is also a very reasonable question to ask from a scientific perspective. After all, some basic physics suggests that you and the rest of the universe are overwhelmingly unlikely to exist. The second law of thermodynamics, that most existentially resonant of physical laws, says that disorder, or entropy, always tends to increase. Entropy measures the number of ways you can rearrange a system's components without changing its overall appearance. The molecules in a hot gas, for example, can be arranged in many different ways to create the same overall temperature and pressure, making the gas a high-entropy system. In contrast, you can't rearrange the molecules of a living thing very much without turning it into a non-living thing, so you are a low-entropy system.

By the same logic, nothingness is the highest entropy state around – you can shuffle it around all you want and it still looks like nothing.

Given this law, it is hard to see how nothing could ever be turned into something, let alone something as big as a universe. But entropy is only part of the story. The other consideration is symmetry – a quality

that appears to exert profound influence on the physical universe wherever it crops up. Nothingness is very symmetrical indeed. "There's no telling one part from another, so it has total symmetry," says physicist Frank Wilczek of the Massachusetts Institute of Technology.

And as physicists have learned over the past few decades, symmetries are made to be broken. Wilczek's own speciality is quantum chromodynamics, the theory that describes how quarks behave deep within atomic nuclei. It tells us that nothingness is a precarious state of affairs. "You can form a state that has no quarks and antiquarks in it, and it's totally unstable," says Wilczek. "It spontaneously starts producing quark-antiquark pairs." The perfect symmetry of nothingness is broken. That leads to an unexpected conclusion, says Victor Stenger, a philosopher at the University of Colorado in Boulder: despite entropy, "something is the more natural state than nothing".

"According to quantum theory, there is no state of 'emptiness'," agrees Frank Close of the University of Oxford. Emptiness would have precisely zero energy, far too exacting a requirement for the uncertain quantum world. Instead, a vacuum is actually filled with a roiling broth of particles that pop in and out of existence. In that sense this magazine, you, me, the moon and everything else in our universe are just excitations of the quantum vacuum.

"Perhaps the big bang was just nothingness doing what comes naturally"

Before the big bang

Might something similar account for the origin of the universe itself? Quite plausibly, says Wilczek. "There is no barrier between nothing and a rich universe full of matter," he says. Perhaps the big bang was just nothingness doing what comes naturally.

This, of course, raises the question of what came before the big bang, and how long it lasted. Unfortunately at this point basic ideas begin to fail us; the concept "before" becomes meaningless. In the words of Stephen Hawking, it's like asking what is north of the north pole.

Even so, there is an even more mind-blowing consequence of the idea that something can come from nothing: perhaps nothingness itself cannot exist.

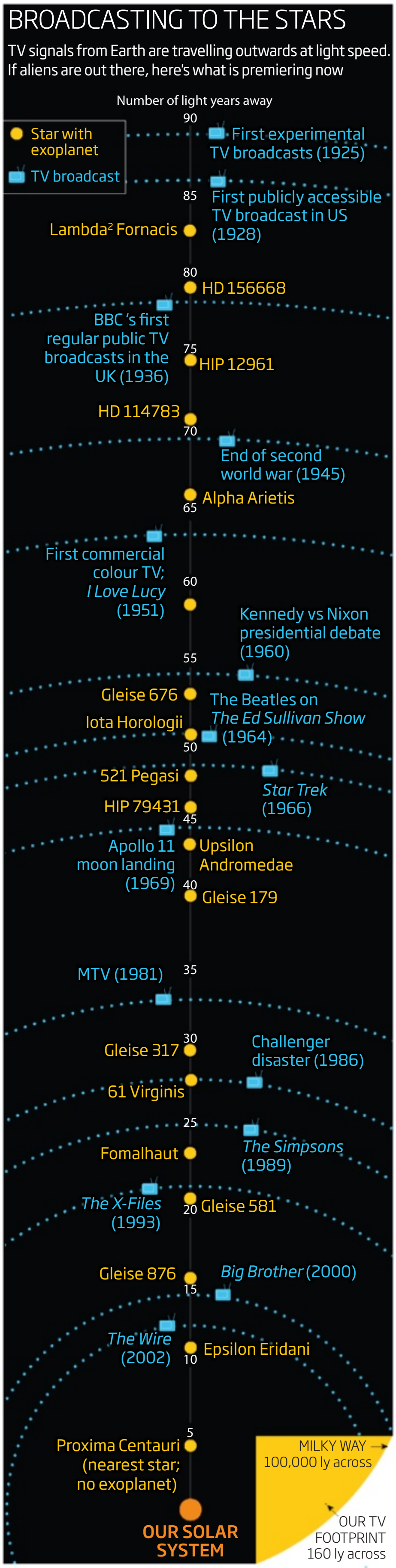
Here's why. Quantum uncertainty allows a trade-off between time and energy, so something that lasts a long time must have little energy. To explain how our universe has lasted for the billions of years that it has taken galaxies to form, solar systems to coalesce and life to evolve into bipeds who ask how something came from nothing, its total energy must be extraordinarily low.

That fits with the generally accepted view of the universe's early moments, which sees space-time undergoing a brief burst of expansion immediately after the big bang. This heady period, known as inflation, flooded the universe with energy. But according to Einstein's general theory of relativity, more space-time also means more gravity. Gravity's attractive pull represents negative energy that can cancel out inflation's positive energy – essentially constructing a cosmos for nothing. "I like to say that the universe is the ultimate free lunch," says Alan Guth, a cosmologist at MIT who came up with the inflation theory in 1981.

Physicists used to worry that creating something from nothing would violate all sorts of physical laws such as the conservation of energy. But if there is zero overall energy to conserve, the problem evaporates – and a universe that simply popped out of nothing becomes not just plausible, but probable. "Maybe a better way of saying it is that something *is* nothing," says Guth.

None of this really gets us off the hook, however. Our understanding of creation relies on the validity of the laws of physics, particularly quantum uncertainty. But that implies that the laws of physics were somehow encoded into the fabric of our universe before it existed. How can physical laws exist outside of space and time and without a cause of their own? Or, to put it another way, why is there something rather than nothing?

Amanda Gefter ■



Are we alone?

HAVE you ever looked up at the night sky and wondered if somebody, or something, is looking back? If perhaps somewhere out there, the mysterious spark we call life has flickered into existence?

Intuitively, it feels as if we can't be alone. For every one of the 2000 stars you can see with your naked eye, there are another 50 million in our galaxy, which is one of 100 billion galaxies. In other words, the star we orbit is just one of 10,000 billion billion in the cosmos. Surely there is another blue dot out there – a home to intelligent life like us? The simple fact is, we don't know.

One way to estimate the number of intelligent civilisations was devised by astronomer Frank Drake. His equation takes into account the rate of star formation, the fraction of those stars with planets and the likelihood that life, intelligent life, and intelligent creatures capable of communicating with us, will arise.

It is now possible to put numbers on some of those factors. About 20 stars are born in the Milky Way every year, and we have spotted more than 1000 planets around stars other than the sun. Estimates suggest that there are 11 billion Earth-like planets orbiting sunlike stars in our galaxy.

But estimating the biological factors is little more than guesswork. We know that life is incredibly adaptable once it emerges, but not how good it is at getting started in the first place.

Unique planet

Some astronomers believe life is almost inevitable on any habitable planet. Others suspect simple life is common, but intelligent life exceedingly rare. A few believe that our planet is unique. "Life may or may not form easily," says physicist Paul Davies of Arizona State University in Tempe. "We're completely in the dark."

So much for equations. What about evidence? Finding life on Mars probably won't help, as it would very likely share its origin with Earthlings. "Impacts have undoubtedly conveyed microorganisms back and forth," says Davies. "Mars and Earth are not independent ecosystems."

Discovering life on Titan would be more revealing. Titan is the only other place in the solar system with liquid on its surface – albeit lakes of ethane. "We are starting to think that if there is life on Titan it would have a separate origin," says Dirk Schulze-Makuch at Washington State University in Pullman. "If we can find a separate origin we can say 'OK, there's a lot of life in the universe'."

Discovering alien microbes in our solar system would be some sort of proof that we are not alone, but what we really want to know is whether there is another intelligence out there. For more than 50 years astronomers have swept the skies with radio telescopes for any hint of a message. So far, nothing.

But that doesn't mean ET isn't there. It just might not know we're here. The only evidence of our existence that reaches beyond the solar system are radio signals and light from our cities. "We've only been broadcasting powerful radio signals since the second world war," says Seth Shostak of the SETI Institute in Mountain View, California. So our calling card has leaked just 70 light years into space, a drop in the ocean. If the Milky Way was the size of London and Earth was at the base of Nelson's Column, our radio signals would still not have left Trafalgar Square.

"It's probably safe to say that even if the local galaxy is choc-a-bloc with aliens, none of them know that *Homo sapiens* is here," says Shostak. That also works in reverse. Given the size of the universe and the speed of light, most stars and planets are simply out of range.

It is also possible that intelligent life is separated from us by time. After all, human intelligence has only existed for a minuscule fraction of Earth's history and may just be a fleeting phase. It may be too much of a stretch to hope that a nearby planet not only harbours intelligent life, but that it does so right now.

But let's say we did make contact with aliens. How would we react? NASA has plans, and most religions claim they would be able to absorb the idea, but the bottom line is we won't know until it happens.

Most likely we'll never find out. Even if Earth is not the only planet with intelligent life, we appear destined to live out our entire existence as if it were – but with a nagging feeling that it can't be. How's that for existential uncertainty? **Valerie Jamieson** ■

TRENT PARKE/MAGNUM PHOTOS

"The entire 3D universe we experience may be encoded in a 2D surface"

Am I a hologram?

TAKE a look around you. The walls, the chair you're sitting in, your own body – they all seem real and solid. Yet there is a possibility that everything we see in the universe – including you and me – may be nothing more than a hologram.

It sounds preposterous, yet there is already some evidence that it may be true, and we could know for sure within a couple of years. If it does turn out to be the case, it would turn our common-sense conception of reality inside out.

The idea has a long history, stemming from an apparent paradox posed by Stephen Hawking's work in the 1970s. He discovered that black holes slowly radiate their mass away. This Hawking radiation appears to carry no information, however, raising the question of what happens to the information that described the original star once the black hole evaporates. It is a cornerstone of physics that information cannot be destroyed.

In 1972 Jacob Bekenstein at the Hebrew University of Jerusalem, Israel, showed that the information content of a black hole is proportional to the two-dimensional surface area of its event horizon – the point of no return for in-falling light or matter. Later, string theorists managed to show how the original star's information could be encoded in tiny lumps and bumps on the event horizon, which would then imprint it on the Hawking radiation departing the black hole.

This solved the paradox, but theoretical physicists Leonard Susskind and Gerard 't Hooft decided to take the idea a step further: if a three-dimensional star could be encoded on a black hole's 2D event horizon, maybe the same could be true of the whole universe. The universe does, after all, have a horizon 42 billion light years away, beyond which point light would not have had time to reach us since the big ›

bang. Susskind and 't Hooft suggested that this 2D "surface" may encode the entire 3D universe that we experience – much like the 3D hologram that is projected from a credit card.

It sounds crazy, but we have already seen a sign that it may be true. Theoretical physicists have long suspected that space-time is pixelated, or grainy. Since a 2D surface cannot store sufficient information to render a 3D object perfectly, these pixels would be bigger in a hologram. "Being in the [holographic] universe is like being in a 3D movie," says Craig Hogan of Fermilab in Batavia, Illinois. "On a large scale, it looks smooth and three-dimensional, but if you get close to the screen, you can tell that it is flat and pixelated."

Quantum fluctuation

A few years ago Hogan looked at readings from an exquisitely sensitive motion-detector in Hannover, Germany, which was built to detect gravitational waves – ripples in the fabric of space-time. The GEO600 experiment has yet to find one, but in 2008 an unexpected jitter left the team scratching their heads, until Hogan suggested that it might arise from "quantum fluctuations" due to the graininess of space-time. By rights, these should be far too small to detect, so the fact that they are big enough to show up on GEO600's readings is tentative supporting evidence that the universe really is a hologram, he claimed.

Bekenstein is cautious: "The holographic idea is only a hypothesis, supported by some special cases," he says. Further evidence may come from a recently completed instrument at Fermilab called the Holometer, which will make the first direct measure of the graininess of space-time.

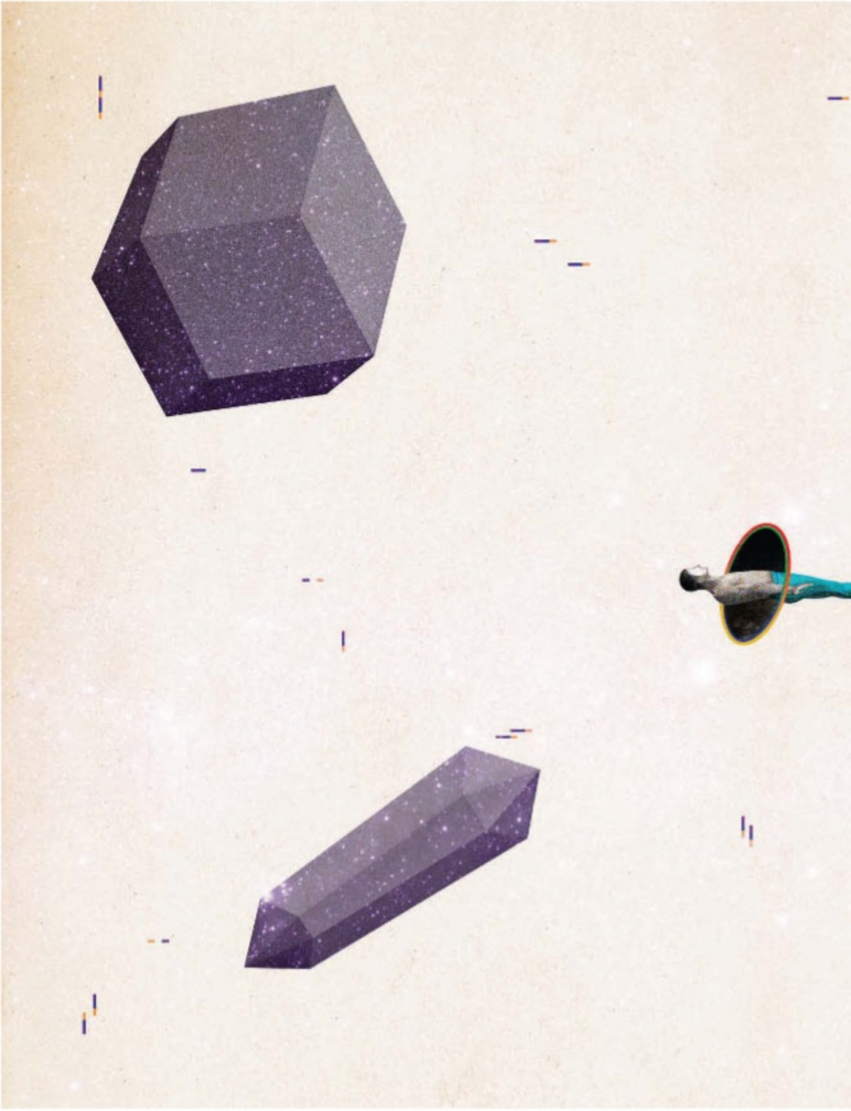
A positive result would challenge every assumption we have about the world we live in. It would show that everything is a projection of something occurring on a flat surface billions of light years away from where we perceive ourselves to be. As yet we have no idea what that "something" might be, or how it could manifest itself in the world we know. Maybe it would make no difference to the way we live our lives, but that seems unlikely. Marcus Chown

Why me?

THINK for a moment about a time before you were born. Where were you? Now think ahead to a time after your death. Where will you be? The brutal answer is: nowhere. Your life is a brief foray on Earth that started one day for no reason and will inevitably end.

But what a foray. Like the whole universe, your consciousness popped into existence out of nothingness and has evolved into a rich and complex entity full of wonder and mystery.

Contemplating this leads to a host of mind-boggling questions. What are the odds of my consciousness existing at all? How can such a thing emerge from nothingness? Is there any possibility of it surviving my death? And what is consciousness anyway?



JIRAYU KOO

Answering these questions is incredibly difficult. Philosopher Thomas Nagel once asked, "What is it like to be a bat?" Your response might be to imagine flying around in the dark, seeing the world in the echoes of high-frequency sounds. But that isn't the answer Nagel was looking for. He wanted to emphasise that there is no way of knowing what it is like for a bat to feel like a bat. That, in essence, is the conundrum of consciousness.

Neuroscientists and philosophers who study consciousness fall into two broad camps. One thinks that consciousness is an emergent property of the brain and that once we fully understand the intricate workings of neuronal activity, consciousness will be laid bare. The other doubts it will be that simple. They agree that consciousness emerges from the brain, but argue that Nagel's question will always remain unanswered: knowing every detail of a bat's brain cannot tell us what it is like to be a bat. This is often called the "hard problem" of consciousness, and seems scientifically intractable – for now.

Meanwhile, "there are way too many so-called easy problems to worry about", says Anil Seth of the University of Sussex in Brighton, UK.

One is to look for signatures of consciousness in brain activity, in the hope that this takes us closer to understanding what it is. Various brain areas have been found to be active when we are conscious of something and quiet when we are not. For example, Stanislas Dehaene of the French National Institute of Health and Medical Research in Gif sur Yvette and colleagues have identified such regions in our frontal and parietal lobes.

"Once we understand the intricate workings of the brain, conscious experience will be laid bare"

Consciousness explained

This is consistent with a theory of consciousness proposed by Bernard Baars of the Neuroscience Institute in California. He posited that most non-conscious experiences are processed in specialised local regions of the brain such as the visual cortex. We only become conscious of this activity when the information is broadcast to a network of neurons called the global workspace – perhaps the regions pinpointed by Dehaene.

But others believe the theory is not telling the whole story. "Does global workspace theory really explain consciousness, or just the ability to report about consciousness?" asks Seth.

Even so, the idea that consciousness seems to be an emergent property of the brain can take us somewhere. For example, it makes the odds of your own consciousness existing the same as the odds of you being born at all, which is to say, very small. Just think of that next time you suffer angst about your impending return to nothingness.

As for whether individual consciousness can continue after death, "it is extremely unlikely that there would be any form of self-consciousness after the physical brain decays", says philosopher Thomas Metzinger of the Johannes Gutenberg University in Mainz, Germany.

Extremely unlikely, but not impossible. Giuilio Tononi of the University of Wisconsin-Madison argues that consciousness is the outcome of how complex matter, including the brain, integrates information. "According to Tononi's theory, if one could build a device or a system that integrated information exactly the same way as a living brain, it would generate the same conscious experiences," says Seth. Such a machine might allow your consciousness to survive death. But it would still not know what it is like to be a bat.

Anil Ananthaswamy ■

MARTIN SOEBY/GALLERYSTOCK

IT HAS been called the Goldilocks paradox. If the strong nuclear force which glues atomic nuclei together were only a few per cent stronger than it is, stars like the sun would exhaust their hydrogen fuel in less than a second. Our sun would have exploded long ago and there would be no life on Earth. If the weak nuclear force were a few per cent weaker, the heavy elements that make up most of our world wouldn't be here, and neither would you.

If gravity were a little weaker than it is, it would never have been able to crush the core of the sun sufficiently to ignite the nuclear reactions that create sunlight; a little stronger and, again, the sun would have burned all of its fuel billions of years ago. Once again, we could never have arisen.

"The most likely explanation of fine-tuning is that our universe is merely one of many"

Such instances of the fine-tuning of the laws of physics seem to abound. Many of the essential parameters of nature – the strengths of fundamental forces and the masses of fundamental particles – seem fixed at values that are "just right" for life to emerge. A whisker either way and we would not be here. It is as if the universe was made for us.

What are we to make of this? One possibility is that the universe was fine-tuned by a supreme being – God. Although many people like this explanation, scientists see no evidence that a supernatural entity is orchestrating the cosmos (see page 46). The known laws of physics can explain the existence of the universe that we observe. To paraphrase astronomer Pierre-Simon Laplace when asked by Napoleon why his book *Mécanique Céleste* did not mention the creator: we have no need of that hypothesis.

Another possibility is that it simply couldn't be any other way. We find ourselves in a universe ruled by laws compatible with life because, well, how could we not?

This could seem to imply that our existence is an incredible slice of luck – of all the universes that could have existed, we got one capable of supporting intelligent life. But most physicists don't see it that way.

The most likely explanation for fine-tuning is possibly even more mind-expanding: that our universe is merely one of a vast ensemble of universes, each with different laws of physics. We find ourselves in one with laws suitable for life because, again, how could it be any other way?

The multiverse idea is not without theoretical backing. String theory, our best attempt yet at a theory of everything, predicts at least 10^{500} universes, each with different laws of physics. To put that number into perspective, there are an estimated 10^{25} grains of sand in the Sahara desert.

Fine-tuned fallacy

Another possibility is that there is nothing to explain. Some argue that the whole idea of fine-tuning is wrong. One vocal critic is Victor Stenger of the University of Colorado in Boulder, author of *The Fallacy of Fine-tuning*. His exhibit A concerns one of the pre-eminent examples of fine-tuning, the unlikeliness of the existence of anything other than hydrogen, helium and lithium.

All the heavy elements in your body, including carbon, nitrogen, oxygen and iron, were forged inside distant stars. In 1952, cosmologist Fred Hoyle argued that the existence of these elements depends on a huge cosmic

coincidence. One of the key steps to their formation is the "triple alpha" process in which three helium nuclei fuse together to form a carbon-12 nucleus. For this reaction to occur, Hoyle proposed that the energy of the carbon-12 nucleus must be precisely equal to the combined energy of three helium nuclei at the typical temperature inside a red giant star. And so it is.

However, Stenger points out that in 1989 a team at the Technion-Israel Institute of Technology in Haifa showed that, actually, the carbon-12 energy level could have been significantly different and still resulted in the heavy elements required for life.

There are other problems with the fine-tuning argument. One is the fact that examples of fine-tuning are found by taking a single parameter – a force of nature, say, or a subatomic particle mass – and varying it while keeping everything else constant. This seems very unrealistic. The theory of everything, which alas we do not yet possess, is likely to show intimate connections between physical parameters. The effect of varying one may very well be compensated for by variations in another.

"The existence of elements other than hydrogen, helium and lithium depends on a coincidence"

Then there is the fact that we only have one example of life to go on, so how can we be so sure that different laws could not give rise to some other living system capable of pondering its own existence?

One example of fine-tuning, however, remains difficult to dismiss: the accelerating expansion of the universe by dark energy. Quantum theory predicts that the strength of this mysterious force should be about 10^{120} times larger than the value we observe.

This discrepancy seems extraordinarily fortuitous. According to Nobel prizewinner Steven Weinberg, if dark energy were not so tiny, galaxies could never have formed and we would not be here. The explanation Weinberg grudgingly accepts is that we must live in a universe with a "just right" value for dark energy. "The dark energy is still the only quantity that appears to require a multiverse explanation," admits Weinberg. "I don't see much evidence of fine-tuning of any other physical constants." **Marcus Chown** ■

A GOLDILOCKS UNIVERSE

The values of many fundamental constants appear to lie within narrow boundaries that allow life to exist. In 2000, the UK's Astronomer Royal Martin Rees boiled them down to six in his book *Just Six Numbers*

NUMBER
N, the ratio of the strengths of two fundamental forces, electromagnetism and gravity
VALUE
about 10^{36}
IN WHAT WAY IS IT FINE-TUNED?
N determines the minimum size of sunlike stars. It tells us how big an object must be before its gravity can overcome the repulsive electromagnetic forces that keep atomic nuclei apart, igniting nuclear fusion. A larger value would not matter very much, but if N were lower, stars would be smaller and burn through their fuel more quickly, making the evolution of life unlikely.

NUMBER
ε, the proportion of the mass of a hydrogen atom that is released as energy when it is fused into helium inside a star
VALUE
0.007
IN WHAT WAY IS IT FINE-TUNED?
The fusion of hydrogen into helium is the first step in forming heavier elements and thus makes complex chemistry, and life, possible. If ε were slightly smaller, nuclear fusion would be impossible and the universe would consist only of hydrogen. If it were slightly larger, all the universe's hydrogen would have been consumed during the big bang and stars would not exist.

NUMBER
Ω, the ratio of the actual density of matter in the universe to the theoretical "critical density" which would cause the universe to collapse eventually under its own gravity
VALUE
about 0.3
IN WHAT WAY IS IT FINE-TUNED?
Ω is one of the factors that determines how fast the universe expands. If it were higher, the universe would have collapsed long ago; if it were lower, expansion would have been too rapid to allow stars and galaxies to form.

NUMBER
λ, the cosmological constant, or the energy that arises from quantum fluctuations of the vacuum
VALUE
about 0.7
IN WHAT WAY IS IT FINE-TUNED?
λ is the leading contender for the mysterious force that is accelerating the expansion of the universe. A smaller value would not be a problem, but if it were much larger the universe would have expanded so rapidly that stars or galaxies would not have had time to form.

NUMBER
Q, the amount of energy it would take to break up a galactic supercluster as a proportion of the total energy stored in all of its matter
VALUE
about 10^{-5}
IN WHAT WAY IS IT FINE-TUNED?
Q is a proxy measure of the size of the tiny fluctuations in the early universe that were eventually amplified into stars and galaxies. If it were smaller the universe would be inert and structureless; larger and the universe would be dominated by black holes by now. Neither case would support life.

NUMBER
D, the number of spatial dimensions
VALUE
3
IN WHAT WAY IS IT FINE-TUNED?
With four spatial dimensions the orbits of planets would be unstable, while life would be impossible with just two.

How do I know I exist?

IN A nutshell, you don't.

Philosopher René Descartes hit the nail on the head when he wrote "cogito ergo sum". The only evidence you have that you exist as a self-aware being is your conscious experience of thinking about your existence. Beyond that you're on your own. You cannot access anyone else's conscious thoughts, so you will never know if they are self-aware.

That was in 1644 and little progress has been made since. If anything, we are even less sure about the reality of our own existence.

It is not so long ago that computers became powerful enough to let us create alternative worlds. We have countless games and simulations that are, effectively, worlds within our world. As technology improves, these simulated worlds will become ever more sophisticated. The "original" universe will eventually be populated by a near-infinite number of advanced, virtual civilisations. It is hard to imagine that they will not contain autonomous, conscious beings. Beings like you and me.

According to Nick Bostrom, a philosopher at the University of Oxford who first made this argument, this simple fact makes it entirely plausible that our reality is in fact a simulation run by entities from a more advanced civilisation.

How would we know? Bostrom points out that the only way we could be sure is if a message popped up in front of our eyes saying: "You are living in a computer simulation." Or, he says, if the operators transported you to their reality (which, of course, may itself be a simulation).

Although we are unlikely to get proof, we might find some hints about our reality. "I think it might be feasible to get evidence that would at least give weak clues," says Bostrom.

Economist Robin Hanson of George Mason University in Fairfax, Virginia, is not so sure. If we did find anything out, the operators could just rewind everything back to a point where the clue could be erased. "We won't ever notice if they don't want us to," Hanson says. Anyway, seeking the truth might even be asking for trouble. We could be accused of ruining our creators' fun and cause them to pull the plug.

Zombie invasion

Hanson has a slightly different take on the argument. "Small simulations should be far more numerous than large ones," he says. That's why he thinks it is far more likely that he lives in a simulation where he is the only conscious, interesting being. In other words, everyone else is an extra: a zombie, if you will. However, he would have no way of knowing, which brings us back to Descartes.

Of course, we do have access to a technology that would have looked like sorcery in Descartes's day: the ability to peer inside someone's head and read their thoughts. Unfortunately, that doesn't take us any nearer to knowing whether they are sentient. "Even if you measure brainwaves, you can never know exactly what experience they represent," says psychologist Bruce Hood at the University of Bristol, UK.

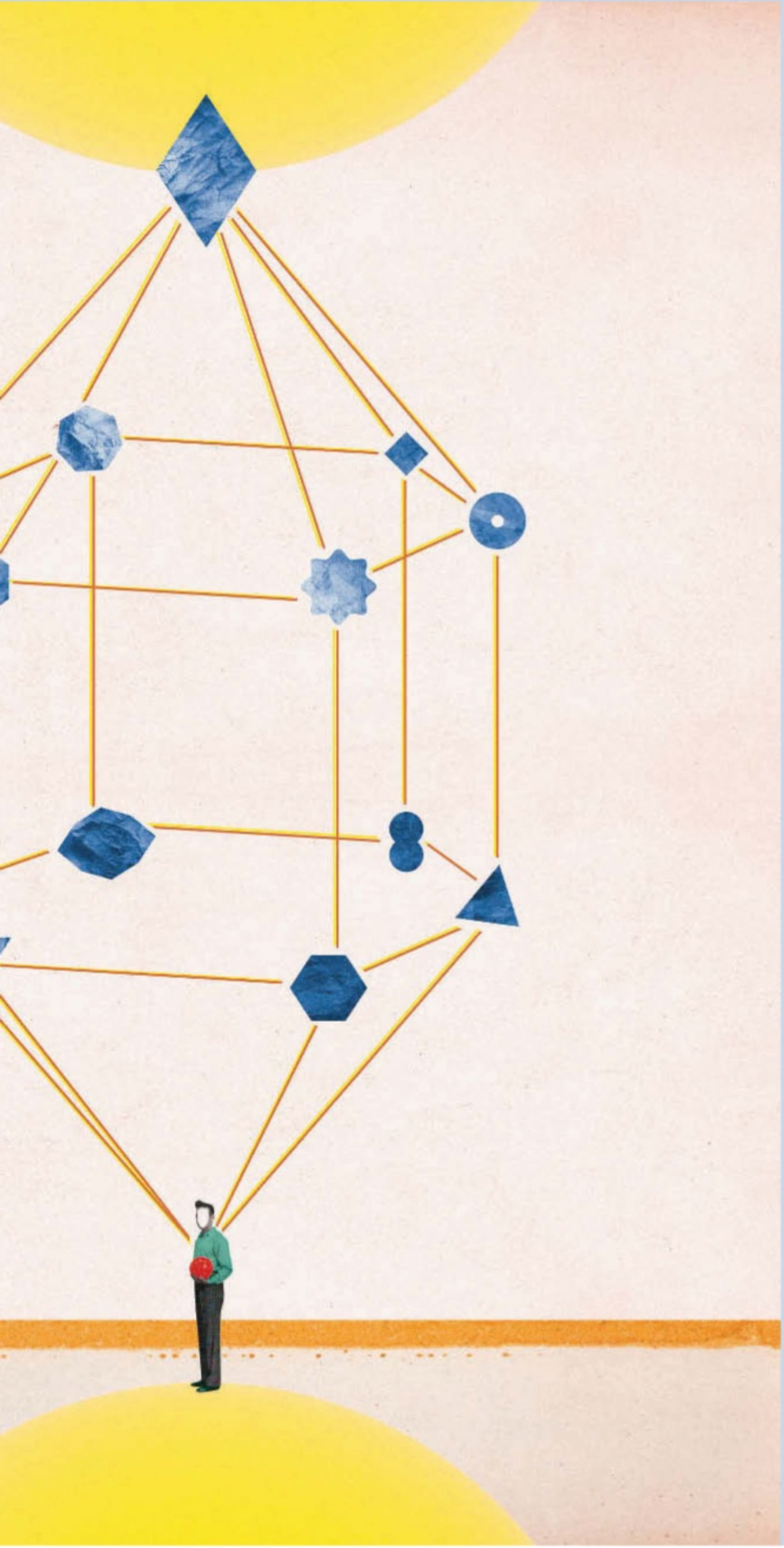
If anything, brain scanning has undermined Descartes's maxim. You, too, might be a zombie. "I happen to be one myself," says Stanford University philosopher Paul Skokowski. "And so, even if you don't realise it, are you."

"I happen to be a zombie myself and even if you don't realise it, so are you"

Skokowski's assertion is based on the belief, particularly common among neuroscientists who study brain scans, that we do not have free will. There is no ghost in the machine; our actions are driven by brain states that lie entirely beyond our control. "I think, therefore I am" might be an illusion.

So, it may well be that you live in a computer simulation in which you are the only self-aware creature. I could well be a zombie and so could you. Have an interesting day.

Michael Brooks ■



Is there more than one me?

FAR, far away, in a galaxy with a remarkable resemblance to the Milky Way, is a star that looks remarkably like the sun. And on the star's third planet, which looks like a twin of the Earth, lives someone who, for all the world, is you. Not only do they look the same as you and lead an identical life, they are reading this exact same article – in fact, they are focused on this very line.

Weird? I've hardly started. In fact, there are an infinite number of galaxies that look just like our own, containing infinite copies of you and your loved ones leading lives, up until this moment, that are absolutely identical to yours.

The existence of these parallel worlds is not just idle speculation. It does not depend on exotic theories such as the multiverse or the "many worlds" interpretation of quantum mechanics, in which the universe constantly bifurcates. It is an unavoidable consequence of the standard theory of our universe.

"Parallel worlds are an unavoidable consequence of our standard theory"

All this needs some explanation. The furthest we can see is the distance light has been able to travel since the universe was born 13.7 billion years ago. Light from objects further away has not arrived yet. They are beyond our cosmic horizon.

Yet we know there is more to the universe. Radiation left over from the big bang appears to confirm that the cosmos went through a fleeting phase of superfast expansion known as inflation. And, according to inflation, there is effectively an infinite amount of universe out there.

So our observable universe is akin to a bubble and beyond it lies an infinite number of other bubbles that have a similarly restricted view. Each one experienced the same big bang we did and has the same laws of physics. Yet the initial conditions were slightly different, so different stars and galaxies congealed out of the cooling debris.

Despite this, finding another universe just like ours seems unlikely. Yet quantum mechanics tells a different story. Zoom in and you'll find that the universe is grainy, with space resembling a chessboard. ›

JIRAYU KOO

"If you could travel far enough you would come across a universe identical to ours"

Immediately after the big bang, our observable universe – our bubble – contained only a few "squares". So there were only a few places for the matter that seeded the formation of today's galaxies.

The neighbouring bubbles contained a slightly different arrangement of matter. So did their neighbours. And so on. But eventually you run out of possible ways to arrange the matter in the bubbles. Eventually you come across an identical bubble to ours. As a result, there are a finite number of ways history can play out. Given that the universe is infinite, there must be a infinite number of histories just like ours, plus an infinite number of different ones.

If you could travel far enough in any direction today, you would eventually come across a universe identical to our observable universe right down to the last detail, including you. Max Tegmark at the Massachusetts Institute of Technology has worked out that to find your closest identical copy you would have to travel $10^{10^{28}}$ metres. That corresponds to 1 followed by 10 billion billion billion zeros.

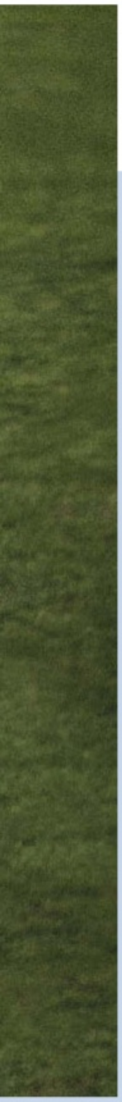
Sadly that means you will never be able to meet your other you. With each passing moment, more of the universe appears over the horizon. Yet by the time our observable universe had expanded to encompass your nearest doppelganger, all the stars will have long burned out.

Remarkably, the only way to evade this bizarre conclusion is if our standard pictures of cosmology and quantum theory are wrong.

Unsettled? You're not alone. Cosmologist Alexander Vilenkin of Tufts University in Medford, Massachusetts, has been working on such ideas for more than 25 years. "I have never been happy with the idea that there are an infinite number of Alexander Vilenkins out there," he says. "Unfortunately, I think it is likely to be true."

It is worth reiterating that this is the most basic and uncontroversial of all conceptions of multiple universes. There are many other "multiverse" theories. For instance, string theory, which views the fundamental building blocks of matter as ultra-tiny, vibrating strings of mass-energy, predicts the existence of other universes. The fact that the universe is apparently fine-tuned for us may be telling us of the existence of other universes with different laws of physics . And then there is the many-worlds interpretation of quantum mechanics in which all possible histories and futures – including yours – play out in separate universes. Many-worlds is a minority view, but if it is true there is a universe somewhere where you are Wimbledon champion.

Tegmark has classified such multiverses into a hierarchy of ever-bigger versions, but nobody yet knows if or how all these versions mesh together. The multiverse is an emerging idea; science in the making. The dust has yet to settle and give us – and our infinite doppelgangers – a consistent and clear picture. Marcus Chown ■



Will we die out?

WRESTLING with mortality is difficult. But it is not just the prospect of personal annihilation that we have the dubious luxury of contemplating. One day, humanity itself will cease to exist. Like all species, we will either become extinct or evolve into something else. From a purely existential perspective the latter sounds infinitely preferable. So what are our chances?

First the good news: time is on our side. The average mammalian species lasts around 1 million years before it evolves into something else or dies out. By that reckoning, *Homo sapiens* has some 800,000 years to play with.

But that's assuming we are just another mammal, destined to follow the usual pattern. It is tempting to think that we have changed the game so drastically that the normal rules do not apply. Have we?

Let's deal with evolution first. There are two key ingredients: variation and selection. The key generator of variation is genetic mutation, and we certainly haven't broken free of that. "If anything, we are probably increasing the rate of mutational change," says Christopher Wills at the University of California, San Diego, noting that our world is awash with human-made mutagens.

But it is conceivable that we have changed the rules of natural selection. In general, individuals who are better adapted to their environment are more likely to survive and pass on their genes. Is that still true for humans when modern medicine and technology have increased everybody's ability to survive?

It seems that it is. Advances in genomic analysis make it clear that natural selection is still alive and kicking. One study found that around 1800 gene variations have become common in the past 50,000 years. Another study found that selection actually accelerated over this time, perhaps because by colonising the world and creating complex cultures we have subjected ourselves to a wide variety of new selection pressures.

"There is no reason to think that humans will stop evolving," says Stephen Stearns at Yale University, whose research reveals continuing evolution in modern populations. "The only question is in what ways will we change as we continue to evolve."

"The only question is in what ways we will change as we continue to evolve"

Without strong, universal forces shaping our entire species, we could evolve aimlessly, but even then the cumulative effects would be significant. Palaeoanthropologist Chris Stringer from the Natural History Museum in London foresees a distant future hundreds of thousands of years from now when our descendants have accrued so many genetic and physical changes that they could no longer interbreed with today's humans, and would therefore be a new species. Presumably it would be recognisable as a hominin, but what exactly it might look like is anybody's guess.

Dramatic events

Dramatic events would speed things up. "A pandemic could swiftly reduce the human population by 90 per cent or more," says philosopher Dan Dennett from Tufts University in Medford, Massachusetts. Depending on who was able to survive, the humans that passed through this bottleneck could emerge as a new species.

Extreme climate change could have the same effect. And if some people left Earth and set up home elsewhere, evolution would almost certainly take them down a different path. Isolated from the rest of humanity and forced to adapt to conditions on a different planet, speciation seems inevitable.

Advances in reproductive technology might allow us to direct our own evolution by picking the characteristics we most desire for our offspring. We could even choose to become superhuman as advances in computing, robotics, biotechnology and nanotechnology enable us to rebuild and extend our bodies and brains. "Very few people will opt out completely," predicts futurologist Ray Kurzweil. "Kind of like the Amish today."

Of course extinction is also a possibility. In the wild, extinctions occur for a variety of reasons, with competition from other species, predation and loss of genetic diversity among the leading causes. Given our huge population and our dominance over other species, none of these seems to be a threat.

But we may well do unto ourselves what we have done to so many other species and cause enough environmental destruction to drive ourselves extinct. We also have no control over phenomena that have wreaked havoc in the past, such as asteroids and supervolcanoes.

Meanwhile, our species' indomitable curiosity may lead us to create a new form of annihilation – perhaps with atomic particles, "grey goo" or a lethal bioengineered life form.

Although we can't predict our future, we can say one thing for certain: our existence is just a passing phase. **Kate Douglas** ■

LARS HANSEN/GALLERYSTOCK

JIRAYU KOO

What happens when we become obsolete?

OUR brains are incredible. They are the most complicated things in the universe that we know of. And yet there is no reason to think that they are anything other than flesh-and-blood machines – which means we should able be build machines that can emulate them. That is the goal of artificial intelligence research – and it could have profound effects on human existence.

Artificial intelligences (AIs) on a human level would probably not remain at that level for long. They are widely expected to become smarter than us before 2050. A few researchers even think it could happen in the next decade.

For the first time, we would no longer be the most intelligent beings on the planet. The consequences could be stupendous. In 1993, the mathematician and science fiction author Vernor Vinge dubbed this point "the singularity", because he saw it as a turning point that would transform the world. So what will happen to us? Nobody really knows. "It's like cockroaches and dogs trying to predict the future of human technology," says Ben Goertzel, leader of OpenCog, an open source project to create AIs with general intelligence.

That hasn't stopped people from considering various scenarios. One distinct possibility is that AIs will exterminate us, which seems especially likely if the first are robots spawned in military labs.

Physicist and author David Deutsch of the University of Oxford has suggested that the way to avoid "a rogue AI apocalypse" is to welcome AIs into our existing institutions. But even if that were feasible, how could we compete with smarter and faster beings capable of working tirelessly 24/7 without ever getting tired or ill? They are likely to rapidly surpass all our scientific, technological and artistic achievements. Our precocious creations would soon end up owning the place.

One way or another, then, AIs look set to take over. One cause for optimism is that they will not be stuck on the planet like us fragile humans. A 1000-year trip to Epsilon Eridani is not so daunting if you can just turn yourself off until you get there. In fact, AIs may prefer to leave Earth. "They will probably work better in space, where it's supercool," says Goertzel.

So we are not necessarily doomed to compete with AIs for energy and resources – a battle we are not likely win. With a galaxy to colonise, they may be content to let us keep our damp little planet. They might be as indifferent to us as we are to ants, or

"Artificial intelligences might be as indifferent to us as we are to ants"

manage Earth as a kind of nature reserve.

That might seem like a futile existence. But most people won't be too bothered by the knowledge that they are inferior, Goertzel thinks – not as long as there's sex, drugs and rock 'n' roll. Some people will continue to do science and art for the sheer joy of it, regardless of how poor their work is in comparison to the machines'.

For Goertzel, the best case scenario would be that the AIs provide a "human reserve" for those who want to stay as they are, while offering those who want it the chance to slowly transform themselves into something more than humans. "You would want it to be a gradual change, so at each step of the way you still feel yourself."

Stay human and die, or transform into a near-immortal superintelligence – what a choice. Michael Le Page ■

Am I the same person I was yesterday?

IT'S THERE when we wake up and slips away when we fall asleep, maybe to reappear in our dreams. It's that feeling we have of being anchored in a body we own and control, and from within which we perceive the world. It's the feeling of personal identity that stretches across time, from our first memories, via the here and now, to some imagined future. It's all of these tied into a coherent whole. It's our sense of self.

Humans have pondered the nature of the self for millennia (see page 95). Is it real or an illusion? And if real, what is it, and where do we find it?

Different philosophical traditions have reached radically different conclusions. At one extreme is the Buddhist concept of "no self", in which you are merely a fleeting collection of thoughts and sensations. At the other are dualist ideas, most recently associated with the philosopher Karl Popper and Nobel laureate and neuroscientist John Eccles. They argued that the self exists as a separate "field" which interacts with and controls the brain.

Modern science, if anything, is leaning towards Buddhism. Our sense of self is not an entity in its own right, but emerges from general purpose processes in the brain.

In 2005, Seth Gillihan and Martha Farah of the University of Pennsylvania in Philadelphia proposed a view of the self that has three strands: the physical self (which arises from our sense of embodiment); the psychological self (which comprises our subjective point of view, our autobiographical memories and the ability to differentiate between self and others); and a higher-level sense of agency, which attributes the actions of the physical self to the psychological self.

We are now uncovering some of the brain processes underlying these strands. For instance, Olaf Blanke of the Swiss Federal Institute of Technology in Lausanne and colleagues have shown that the physical sense of self is centred on the temporo-parietal cortex. It integrates information from your senses to create a sense of embodiment, a feeling of being located in a particular body in a particular place. That feeling can be spectacularly disrupted if the temporo-parietal cortex receives contradictory inputs, causing it to generate out-of-body experiences.

Being in charge

It is proving harder to find the site of our sense of agency – that feeling of being in charge of our actions. In one functional MRI study volunteers with joysticks moved images around on a computer screen. When the volunteer felt he or she had initiated the action, the brain's anterior insula was activated but the right inferior parietal cortex lit up when the volunteer attributed the action to the experimenter.

But other researchers, using different experiments, have identified many more brain regions that seem to be responsible for the sense of agency.

Within the brain, it seems, the self is both everywhere and nowhere. "If you make a list [for what's needed for a sense of self], there is hardly a brain region untouched," says cognitive philosopher Thomas Metzinger of Johannes Gutenberg University in Mainz, Germany. Metzinger interprets this as meaning the self is an illusion. We are, he says, fooled by our brains into believing that we are substantial and unchanging.

Mental disorders also make it abundantly clear that this entity that we regard as inviolate is not so. For example, those suffering from schizophrenia harbour delusions that experiences and thoughts are being implanted in their brain by someone or something else.

"In some sense, it's a disorder of the self, because these people are doing ›

things, but they are not feeling as if they themselves are doing them," says Anil Seth of the University of Sussex in Brighton, UK. "That's a disorder of [the sense of] agency."

Another striking condition is depersonalisation disorder, in which people feel a persistent sense of detachment from their body and thoughts.

"Even the narrative we have of ourselves growing up is error-prone"

Even the narrative we have of ourselves as children growing up, becoming adults and growing old, which is carefully constructed from our bank of autobiographical memories, is error-prone. Studies have shown that each time we recall an episode from our past, we remember the details differently, thus altering our selves.

So the self, despite its seeming constancy and solidity, is constantly changing. We are not the same person we were a year ago and we will be different tomorrow or a year from now. And the only reason we believe otherwise is because the brain does such a stellar job of pulling the wool over our eyes.
Anil Ananthaswamy ■

YOUR TEMPORARY BODY

YOUR lifelong sense of self is intimately tied to your body, but how much of that body stays with you for life? The answer is surprisingly little. If you live to be, say, 75 years old, the vast majority of your body will be younger than "you" are.

The cells lining your gut, for example, are replaced about every five days. The outer layer of your skin turns over every two weeks and you get a new set of red blood cells every four months. That is not so surprising given that these cells are on the front line of wear and tear. But the rest of your body also needs a refit from time to time.

Using a variant of carbon dating, a team led by Jonas Frisén at the Karolinska Institute in Stockholm, Sweden, have discovered that the average age of a bone cell is 10 years, a muscle cell 15 years and a fat cell about 9.5 years. Your heart cells are on average six years younger than you; if you live beyond 50 about half of the cells in your heart will have been replaced.

The exception is your brain, most of which stays with you for life. But renewal happens here too. There are cells in your cerebellum and hippocampus that are younger than you.

All of which puts the idea of lifelong personal identity into perspective. Imagine being given a car on the day you are born. Over the next 70 years you gradually replace almost every part, from the tailpipe to the headlights. A few bits and pieces remain, but is it really the same car? Think about it. Graham Lawton ■

How will it all end?

MILONEWMAN/MILLENNIUMIMAGES.UK

IT IS three weeks after the end of time, and at the Post-Universe Conference of Cosmology and Other Loose Ends, Professor Adams is standing in front of a restless audience telling them in smug tones what they already know. The universe ended in precisely the way that his own theory predicted, in a rather uncomfortable event known as the "Big Slurp".

Of course, by definition there can be no such meeting and no way to prove or disprove a theory about the end of all things. But this untestable question tugs at our morbid curiosity. In recent years physicists have been peering deep into the tea leaves of time to try to foretell our ultimate fate. Will the universe be finished off by a big freeze, a big rip, a big crunch… or a big something else?

"The foundations would be yanked from under us; we would cease to exist"

To make a first attempt at this long-range forecast, we can just extrapolate current trends. Today's universe is expanding, and the expansion is accelerating as the repulsive agent called dark energy takes hold. Projecting our ballooning universe into the future, we seem to be doomed to a dingy end. Most of known space will fly off into the darkness, isolating our local group of galaxies in its own lonely pocket universe. The stars will fade and eventually matter itself may fall apart as protons decay, leaving behind nothing but a wispy gas of fundamental particles, ever-more tenuous and ever colder.

Or it could be worse. We don't know what dark energy is, so we don't know whether it will remain constant into the distant future. The repulsion might get stronger as space expands. If this growing "phantom energy" really gets going, the eventual end will come in a split second of cosmic violence called the big rip, as planets, molecules and finally subatomic particles are shredded. Then again, some form of attractive cosmic force could arise to overpower today's repulsion and pull the galaxies back together again, crushing everything to a point of infinite density – a big crunch.

Fortunately, neither of these violent ends will happen any time soon. Observations show that dark energy is changing slowly if at all, implying that a big rip or big crunch is probably tens of billions of years away at least.

An even more disquieting possibility could be just around the corner, however. The very nature of space-time may be unstable. According to string theory, for example, the vacuum of space seems to be free to adopt any of a bewildering variety of different states, which would support different kinds of forces and particles, even different numbers of dimensions. Our apparently firm reality might suddenly decay into a state with lower energy. The foundations of our existence would suddenly be yanked from under us and we, along with any familiar forms of matter, would cease to exist.

Transmogrification

If the vacuum does decay, it will happen at some point in space first, and then race outwards in a spherical shock-front of grisly transmogrification travelling at just a tiny fraction less than the speed of light. In theory we would get some warning of approaching doom, but not a lot. "Much less than a microsecond," says cosmologist Alexander Vilenkin of Tufts University in Medford, Massachusetts. At this very moment a wave of ultimate weirdness might be turning the moon into ectoplasm and bearing down on Earth.

Vilenkin thinks that such an end is almost inevitable; that unless a big rip gets us first, the vacuum will eventually drop into a negative energy state. After the transformation, space would then exert strong gravity of its own, pulling what's left of the universe into a big crunch.

That, however, need not be the end of everything. If our own universe is merely one within an ever-branching and growing multiverse, as some theories predict, then the cosmos as a whole will endure even if each of its branches has a limited lifespan. And for our local universe there remains the hope of resurrection. Today's physical theories break down at a big crunch or a big rip, allowing the possibility that a new universe could rise from the ashes (in a big bounce, or some other big as-yet-unnamed thing). And in the case of a big freeze, there will be so much time to play with that a random quantum fluctuation might spark a whole new big bang. Perhaps that impossible cosmology conference could happen after all. Perhaps existence will never end. Stephen Battersby ■


WESTMAC/ORIGINAL IMAGES: PHOTOALTO/JAMES HARDY/GETTY

CHAPTER THREE

God

Can't live with him, can't live without him.

In our enlightened world, god is still everywhere. In the US, religion remains a fixture of public life. Even in secular Europe, arguments rage over religious identity and militant atheism. Try as we might, we just don't seem able to let go.

Perhaps that is because we have been looking at god the wrong way. Atheists often see gods and religion as being imposed from above, like a totalitarian regime. But religious belief is more subtle and interesting than that. In recent years a new scientific vision has emerged that promises to, if not resolve ancient tensions, at least reset the terms of the debate.

Like it or not, religious belief is part of human nature. And a good thing too: without it, we would still be living in the Stone Age.

Viewing religion this way opens up new territory in the battle between science and religion, not least that religion is much more likely to persist than science.

Of course, the truth or otherwise of religion is not a closed book to science: the existence of a deity can be treated as a scientific hypothesis.

Meanwhile, society is gradually learning to live without religion by replicating its success at binding people together. This is something secularists ought to take seriously. Only by understanding what religion is and is not can we ever hope to move on.

RICHARD WILKINSON

Born believers

Our minds solve fundamental problems in a way that leaves a god-shaped space waiting to be filled, says Justin L. Barrett

BY THE time he was 5 years old, Wolfgang Amadeus Mozart could play the clavier and had begun to compose his own music. Mozart was a "born musician"; he had prodigious natural talent and required only minimal exposure to music to become fluent.

Few of us are quite so lucky. Music usually has to be drummed into us by teaching, repetition and practice. And yet in other domains, such as language or walking, virtually everyone is a natural; we are all "born speakers" and "born walkers".

So what about religion? Is it more like music or language?

Drawing upon research in developmental psychology, cognitive anthropology and particularly the cognitive science of religion, I argue that religion comes nearly as naturally to us as language. The vast majority of humans are "born believers", naturally inclined to find religious claims and explanations attractive and easily acquired, and to attain fluency in using them. This attraction to religion is an evolutionary by-product of our ordinary cognitive equipment, and while it tells us nothing about the truth or otherwise of religious claims, it does help us see religion in an interesting new light.

"When it comes to the origin of natural things, children are very receptive to explanations that invoke design or purpose"

As soon as they are born, babies start to try to make sense of the world around them. As they do so, their minds show regular tendencies. From birth children show certain predilections in what they pay attention to and what they are inclined to think.

One of the most important of these is to recognise the difference between ordinary physical objects and "agents" – things that can act upon their surroundings. Babies know that balls and books must be contacted in order to move, but agents such as people and animals can move by themselves.

Because of our highly social nature we pay special attention to agents. We are strongly attracted to explanations of events in terms of agent action – particularly events that are not readily explained in terms of ordinary causation.

For instance, Philippe Rochat and colleagues at Emory University in Atlanta, Georgia, conducted a series of experiments showing that in the first year of life, children distinguish between the movement of ordinary objects and the movement of agents, even if the objects and agents in question are only computer-animated coloured discs. By 9 months old, babies showed that they were not just sensitive to the causal relationship between two discs that appeared to chase one another, but could also tell who was chasing whom (so to speak). The babies first watched either a red disc chasing a blue one or vice versa until they got habituated – good and bored, in other words. Then the experimenter reversed the chase. The babies noticed the difference and started watching again.

Many of these experiments used animated discs that did not remotely resemble a human or animal. Babies do not need a person, or even an animal, present to get their agency reasoning up and running – an important point if they are going to apply their reasoning about agents to invisible gods.

Babies also seem sensitive to two other important features of agents that allow them to understand the world but also make them receptive to gods. First, agents act to attain goals. And second, they need not be visible. In order to function in social groups, avoid predators and capture prey, we must be able to think about agents we cannot see.

The ease with which humans employ agent-based reasoning does not end with childhood. In an experiment I did with Amanda Johnson of Calvin College in Grand Rapids, Michigan, we asked college students to narrate their actions while placing ball bearings over holes on a board. Periodically an electromagnet sent the ball bearings racing around in violation of intuitive physical expectations. Almost two-thirds of the students spontaneously referred to the ball bearings as if they were agents, making comments such as, "That one did not want to stay", "Oh, look. Those two kissed", and "They are not cooperating".

This hair-trigger agent reasoning and a natural propensity to look for agents in the world around us are part of the building blocks for belief in gods. Once coupled with some other cognitive tendencies, such as the search for purpose, they make children highly receptive to religion.

What's a tiger for?

Deborah Kelemen of Boston University in Massachusetts has shown that from childhood we are very attracted to purpose-based explanations of natural objects – from monkeys and people to trees and icebergs. Four and 5-year-olds thought it more sensible that a tiger was "made for eating and walking and being seen at the zoo" than that "though it can eat and walk and be seen at the zoo, that's not what it's made for".

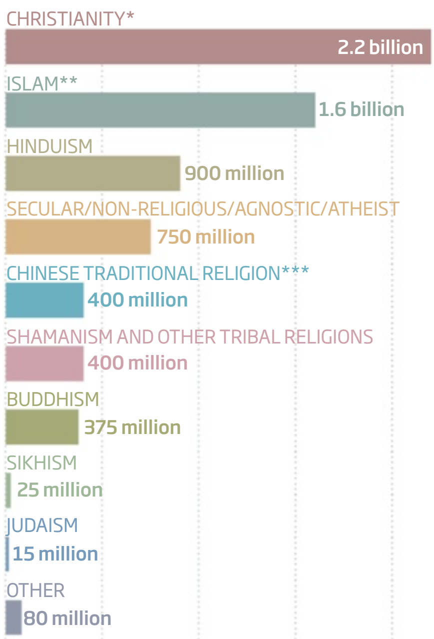
Similarly, when it comes to speculation about the origins of natural things, children are very receptive to explanations that invoke design or purpose. It seems more sensible to them that animals and plants were brought about for a reason than that they arose for no reason.

Margaret Evans of the University of Michigan in Ann Arbor has found that children under 10 tend to embrace creationist explanations of living things over evolutionary ones – even children whose parents and teachers endorse evolution. Kelemen has ›

ANTONINO BARTUCCIO/SIME/4 CORNERS

Who believes what

The world's belief systems by approximate number of adherents



*includes 1.1billion Roman Catholics, 750 million Protestants and 250 million Orthodox Christians

*includes 1.4 billion Sunni and 200 million Shia

***Includes Confucianism, Taoism and Chinese Buddhism

also done experiments with adults that suggest we do not simply outgrow this attraction but that it must be forcibly tamped down through formal education.

It appears that we all share an intuition that apparent order and design, such as we see in the world around us, requires an agent to bring it about. A recent experiment by George Newman of Yale University supports this view. Twelve to 13-month-old babies viewed two animations: a ball knocking over a stack of blocks (obscured by a barrier during the actual striking), and vice versa with the blocks starting in a disordered heap and finishing in a neat stack. Adults would immediately see something unexpected in the second scenario: balls cannot stack blocks. Babies were also surprised, in that they looked longer at the second animation. This suggests that babies find a ball creating order more surprising than a ball creating disorder.

More interesting still was a second version of the experiment. In this, a ball-shaped object with a face moved purposefully behind the barrier and either apparently ordered or disordered the blocks. In this case, the babies found neither display more surprising.

The most straightforward explanation is that babies have the same intuitions as adults: people, animals, gods or other agents can create order or disorder, but non-agents, such as storms or rolling balls, only create disorder.

Of course gods do not just create or order the natural world, they typically possess superpowers: superknowledge, superperception and immortality. Surely these properties of gods – because they differ from and exceed the abilities of people – are difficult for children to adopt?

If anything, the opposite appears to be the case. Children appear to presume that all agents have superknowledge, superperception and immortality until they learn otherwise.

For example, in a 2008 study in Mexico led by Nicola Knight of the University of Oxford, Maya children aged 4 to 7 were shown a gourd that usually holds tortillas. With the opening covered, the experimenter asked children what was inside. After answering "tortillas", they were shown – much to their surprise – that it actually contained boxer shorts.

The experimenter then covered the opening again and asked whether various agents would know what was inside. The agents were the Catholic god, known as Diyoos, the Maya sun god, the forest spirits, a bogeyman-like being called Chiichi' and a human. In Mayan culture, Diyoos is all-seeing and all-knowing, the sun god knows everything that happens under the sun, the forest spirits' knowledge is limited to the forest and Chiichi' is just a nuisance.

The youngest children answered that all the agents would know what was in the gourd. By age 7, the majority thought that Diyoos would know that the gourd contained shorts but the human would think it contained tortillas. They were also sensitive to shades of difference in the other supernatural agents' level of knowledge. Similar things have been found with Albanian, Israeli, British and American children.

I may be wrong, but my interpretation of these findings is that young children find it easier to assume that others know, sense and remember everything than to figure out precisely who knows, senses and remembers what. Their default position is to assume superpowers until teaching or experience tells them otherwise.

This assumption is related to the development of a faculty called "theory of mind", which concerns our understanding of others' thoughts, perception, wants and feelings. Theory of mind is important to social functioning but it takes time to develop. Some 3-year-olds and many 4-year-olds simply assume that others have complete, accurate knowledge of the world.

A similar pattern is seen with children's understanding of the inevitability of death. Studies led by Paul Harris of the Harvard

Graduate School of Education suggest that the default assumption is that others are immortal.

The finding that the younger Maya children thought all the gods would know what was in the gourd is important for another reason: simple indoctrination cannot account for it. Whatever some people say, children do not need to be indoctrinated to believe in god. They naturally gravitate towards the idea.

My contention is that these various features of developing minds – an attraction to agent-based explanations, a tendency to explain the natural world in terms of design and purpose and an assumption that others have superpowers – makes children naturally receptive to the idea that there may be one or more god which helps account for the world around them.

It is important to note that this concept of religion deviates from theological beliefs. Children are born believers not of Christianity, Islam or any other theology but of what I call "natural religion". They have strong natural tendencies toward religion, but these tendencies do not inevitably propel them towards any one religious belief.

Instead, the way our minds solve problems generates a god-shaped conceptual space waiting to be filled by the details of the culture into which they are born. ■

The Santa delusion

Out of the minds of babes and infants comes the idea of god

IF RELIGION comes naturally to children, doesn't that put God on the same footing as Santa Claus or the Tooth Fairy – a being that children should outgrow? And does it not also mean that belief in God is childish?

Let's examine these claims. The analogy begins to weaken when we recognise that many adults come to believe in God having rejected the idea as children, or after rethinking their childhood beliefs and embracing them as adults. That is, they sometimes reason their way to religious beliefs. People do not begin or resume believing in Father Christmas in adulthood.

Santa and the Tooth Fairy also fail to fully fit the conceptual space that children (and adults) have because of their natural cognition. They do not readily account for perceived order and purpose in the natural world, for great fortune and misfortune, for matters concerning morality, life, death and the afterlife and they have little relevance in day-to-day matters outside their very limited ranges of concern – that is, Christmas presents and compensation for lost teeth. Their superknowledge and superperception is circumscribed in curious ways. Santa knows if you've been bad or good but does he know all that you do? The Tooth Fairy knows when you have lost a tooth but not where you have put your car keys.

Note, too, that adults do not typically eat sacrifices placed out for gods and pretend that the gods ate them the way they eat Santa's cookies. If indoctrination and theatrical acts of deception were the bulk of what gods had going for them conceptually, adults would outgrow them too.

It is easy to be sympathetic to the idea that we should abandon "childish" thinking in adulthood. But why does labelling an idea childish automatically make it bad, dangerous or wrong? It is true that children know less than adults and make more mistakes in reasoning, so their judgements are not as trustworthy. But what follows from this is only that we should more carefully scrutinise the beliefs of children than those of adults, particularly if they deviate from what adults believe.

But adults generally do believe in gods. That such belief begins in childhood and typically endures into adulthood places it in the same class as believing in the permanence of solid objects, the continuity of time, the predictability of natural laws, the fact that causes precede effects, that people have minds, that their mothers love them and numerous others. If believing in gods is being childish in the same respect as holding these sorts of beliefs, then belief in gods is in good company.

AFP/GETTY

VINCENT J. MUSI/NGSIMAGES

The idea that launched a thousand civilisations

Without religion we would still be living in the Stone Age, says Ara Norenzayan

ON A hilltop in what is now south-eastern Turkey rests the world's oldest temple of worship. With its massive, T-shaped stone pillars carved with images of animals, Göbekli Tepe is challenging long-held assumptions about the origins of civilisation. While archaeologists are unearthing clues and debating their meaning, the significance of the site escapes no one.

No evidence of agriculture has been found at the site, which may be explained by the fact that it dates back about 11,500 years, making it old enough to have been built by hunter-gatherers. Yet the monumental architecture of Göbekli Tepe would have required the participation of many hundreds, possibly thousands, of people. It may therefore hold clues to two of the deepest puzzles of human civilisation: how did human societies scale up from small, mobile groups of hunter-gatherers to large, sedentary societies? And how did organised religions spread to colonise most minds in the world?

The first puzzle is one of cooperation. Up until about 12,000 years ago all humans lived in relatively small bands. Today, virtually everyone lives in vast, cooperative groups of mostly unrelated strangers. How did this happen?

In evolutionary biology, cooperation is usually explained by one of two forms of altruism: cooperation among kin and reciprocal altruism – you scratch my back and I'll scratch yours. But cooperation among strangers is not easily explained by either.

As group size increases, both forms of altruism break down. With ever-greater chances of encountering strangers, opportunities for cooperation among kin decline. Reciprocal altruism – without extra safeguards such as institutions for punishing freeloaders – also rapidly stops paying off.

The second puzzle is how certain religious traditions became so widespread. If you are Christian, Muslim, Jewish, Hindu, Buddhist, or an agnostic or atheist descendant of any of these, you are the heir to an extraordinarily successful religious movement that started as an obscure cultural experiment.

"Many are called, but few are chosen," says the Gospel according to Matthew. This might

Göbekli Tepe in Turkey, a temple at the dawn of civilisation

as well describe the law of religious evolution, which dictates that while legions of new religious entities are created, most of them die out, save a potent few that survive and flourish.

In the long run, almost all religious movements fail. In one analysis of the stability of 200 utopian communes, both religious and secular, in 19th-century America, Richard Sosis of the University of Connecticut in Storrs found a striking pattern. The average lifespan of the religious communes was a mere 25 years. In 80 years, 9 out of 10 had disbanded. Secular communes, most of which were socialist, fared even worse: they lasted for an average of 6.4 years and 9 out of 10 disappeared in less than 20 years.

Göbekli Tepe suggests an elegant solution to both puzzles: each answers the other. To understand how, we need to revisit the lively debates about the evolutionary origins of religion.

A growing view is that religious beliefs and rituals arose as an evolutionary by-product of ordinary cognitive functions (see page 39). Once that happened, the stage was set for rapid cultural evolution that eventually led to large societies with "Big Gods".

Some early cultural variants of religion presumably promoted prosocial behaviours such as cooperation, trust and self-sacrifice while encouraging displays of religious devotion, such as fasts, food taboos, extravagant rituals and other "hard-to-fake" behaviours which reliably transmitted believers' sincere faith, and signalled their intention to cooperate. Religion thus forged anonymous strangers into moral communities tied together with sacred bonds under a common supernatural jurisdiction.

In turn, such groups would have been larger and more cooperative, and hence more successful in competition for resources and habitats. As these ever-expanding groups grew they took their religions with them, further ratcheting up social solidarity in a runaway process that softened the limitations on group size imposed by kinship and reciprocity.

From there it is a short step to the morally concerned Big Gods of the major world religions. People steeped in the Abrahamic faiths are so accustomed to seeing a link between religion and morality that it is hard for them to imagine that religion did not start that way. Yet the gods of the smallest hunter-gatherer groups, such as the Hadza of east Africa and the San of the Kalahari, are unconcerned with human morality. In these transparent societies where face-to-face interaction is the norm, it is hard to escape the social spotlight. Kin altruism and reciprocity are sufficient to maintain social bonds.

> ***"While legions of new religions are created, most of them die out save for a potent few that survive and flourish"***

However, as groups expand in size, anonymity invades relationships and cooperation breaks down. Studies show that feelings of anonymity – even illusory ones, such as those created by wearing dark glasses – are the friends of selfishness and cheating. Social surveillance, such as being in front of a camera or an audience, has the opposite effect. Even subtle exposure to drawings resembling eyes encourages good behaviour towards strangers. As the saying goes, "watched people are nice people".

It follows, then, that people play nice when they think a god is watching them, and those around them (see "In atheists we distrust", left). The anthropological record supports this idea. In moving from the smallest-scale human societies to the largest and most complex, Big Gods – powerful, omniscient, interventionist watchers – become increasingly common, and morality and religion become increasingly intertwined.

Quentin Atkinson of the University of Auckland, New Zealand, and Harvey Whitehouse of the University of Oxford have found a similar shift in ritual forms: as societies get larger and more complex, rituals become routine and are used to transmit and reinforce doctrines. Similarly, notions of supernatural punishment, karma,

In atheists we distrust

One of the most persistent but hidden prejudices tied to religion is intolerance of atheists. Surveys consistently find that in societies with religious majorities, atheists have one of the lowest approval ratings of any social group, including members of other religions.

This intolerance has a long history. Back in 1689, Enlightenment philosopher John Locke wrote in *A Letter Concerning Toleration*: "Those are not at all to be tolerated who deny the Being of a God. Promises, Covenants, and Oaths, which are the Bonds of Humane Society, can have no hold upon an Atheist."

Why do believers reject atheists, who are not a visible, powerful or even a coherent social group? The answer appears to be the same force that helped religions expand while maintaining social cohesion: supernatural surveillance.

My colleagues and I have found that Locke's intuition – that atheists cannot be trusted to cooperate – is the root of the intolerance. Outward displays of belief in a watchful God are viewed as a proxy for trustworthiness. Intolerance of atheists is driven by the intuition that people behave better if they feel that a God is watching them.

While atheists think of their disbelief as a private matter of conscience, believers treat their absence of belief in supernatural surveillance as a threat to cooperation and honesty.

damnation and salvation, and heaven and hell are common in modern religions, but relatively infrequent in hunter-gatherer cultures.

Several lines of experimental evidence point in the same direction. In one study, children were instructed not to look inside a box, and then left alone with it. Those who had been told that a supernatural agent called Princess Alice was watching, and actually believed in her existence, were much less likely to peek.

Economic games have also been used to probe prosocial behaviour. The dictator game, for example, involves two anonymous players in a one-off transaction. Player 1 is given some money and must decide how much of it to give to player 2. Player 2 receives Player 1's gift (or nothing) and the game ends. Experiments by Joseph Henrich of the University of British Columbia in Vancouver, Canada, and his colleagues found that, across 15 diverse societies from all over the world, believers in the Abrahamic God gave away more money than those who believed in local deities who are not as omniscient and morally concerned.

Along with my colleague Azim Shariff, now at the University of Oregon in Eugene, I planted thoughts of God in people before they played the dictator game by subtly exposing them to words such as divine, God and spirit. Other participants played the game without religious prompts. The reminders of God had a powerful effect. Most people in the unexposed group pocketed all the money but those primed to think of God were much more generous. With another colleague, Will Gervais, now at the University of Kentucky in Lexington, I found that religious reminders heightened believers' feelings of being under surveillance.

Religion, with its belief in watchful gods and extravagant rituals and practices, has been a social glue for most of human history. But recently some societies have succeeded in sustaining cooperation with secular institutions such as courts, police and mechanisms for enforcing contracts. In some parts of the world, especially Scandinavia, these institutions have precipitated religion's decline by usurping its community-building functions. These societies with atheist majorities – some of the most cooperative, peaceful and prosperous in the world – have climbed religion's ladder and then kicked it away.

Subtle reminders of secular moral authority, words such as civic, jury and police, have the same fairness-promoting effect as reminders of God in the dictator game. People have discovered new ways to be nice to each other without a watchful God. ■

Natural religion, unnatural science

STEVE MCCURRY/MAGNUM

Hard-to-fake displays of devotion look bizarre to outsiders but help bind people together

Those who would dance on religion's grave are underestimating its staying power, says Robert N. McCauley

THE human mind has no specific department for religion. Instead, religions appear to be a by-product of various cognitive systems that evolved for unrelated reasons. Research on the cognitive foundations of religious thought has spawned insights about religion itself, as well as providing a fresh perspective on the long-standing project of comparing religion and science.

From an early age humans confront numerous fundamental problems that must be solved in order for them to function in the world. These include distinguishing between inanimate objects and "agents" that can act on their surroundings, recognising faces, avoiding contaminants, parsing speech and reading other people's intentions. By the time children are 6 or 7 years old, their cognitive systems for solving these problems are mostly up and running (see page 39).

Such cognitive systems are "maturationally natural"; they emerge without effort and virtually define normal cognitive development. Although culture infiltrates them – for example, determining the language a child learns – acquiring them does not depend upon instruction or education.

Maturationally natural systems are also what Nobel prizewinning psychologist Daniel Kahneman calls "fast" – they operate automatically and effortlessly. Because of this, they are highly susceptible to false positives. For example, our hair-trigger system for detecting human forms leads us to see faces in the clouds, and our "agency detection device" leads us to talk to our computers and cars.

These rapid and automatic systems also make people receptive to religions. Humans are ready to leap at, swallow and digest religious stories like a hungry frog will leap at, swallow and (attempt to) digest a ball bearing that flies within reach.

Successful religions are adept at engaging these dispositions. Supernatural beings trigger our natural beliefs about agents, and our theory of mind. Sacred spaces and objects cue our involuntary precautions against contaminants; it is no coincidence that so many religious rituals involve cleansing and purification.

Similar elements have recurred in religious systems throughout human history all over the world. New religions pop up all the time but the ones that last mostly stir in the same old ingredients. These recurrent themes – myth, ritual, sacred spaces, belief in supernatural agents and so on – are the elements of what I call popular religion.

None of this, however, bars the application of Kahneman's "slow" forms of thought to religion. Deliberate, conscious reflection about the meaning and truth of religious claims is called theology. Theologians try to make intellectual sense of the enigmatic claims of popular religion. They reflect, debate and sometimes generate abstract formulations that religious and political authorities decide to label as doctrines. Not all religions have theology but many do, especially the proselytising Abrahamic ones.

Unlike popular religion, theology routinely makes abstract and radically counterintuitive statements that are conceptually complex and difficult to understand: God is three persons in one, for example, or a disembodied person who is present everywhere at once. In addition, theological proposals are not at all memorable compared with, say, a story about Jesus's virgin birth. This is why religious people must often make an effort to memorise them and why religious leaders adopt a variety of measures to indoctrinate and police "theological correctness". These include everything from religious education and catechisms to inquisitions.

"The religions that the vast majority of people actually practise are not the same as the doctrines they learn"

Maintaining theological correctness is difficult, however, as the mental systems that underpin popular religion consistently intrude. The consequence is that theological incorrectness is inevitable: the religions that the vast majority of people actually practise are not the same as the doctrines they learn and recite.

Theological incorrectness is seen across cultures and religious systems. When asked in experiments to talk or think about gods' thoughts and actions in stories, religious people immediately and completely abandon theologically correct doctrines in favour of popular religion – even if they have just affirmed and recited those doctrines. The way they think and talk reveals that they see God as more like Superman than the omniscient, omnipresent and omnipotent ruler of the universe in whom they say they believe.

This view of popular religion offers a new perspective on the project of comparing religion and science. It suggests that science poses no threat whatsoever to the persistence of religion. The fears and trepidation of so many believers – and the jubilant anticipation of so many critics of religion – that science will eventually displace ›

religion are wrong-headed on many counts.

First, they underestimate the power and pervasiveness of maturationally natural cognition. Not everyone is religious, but religious ideas and actions spontaneously and inevitably arise in human populations.

Second, they underestimate the creativity and imaginativeness of theology, and so its ability to accommodate any change in our understanding of the universe that science produces. Theologians eventually accommodated our displacement from the centre of things by Copernicus, Galileo and Darwin. It took some time because of the size of the challenge, but it happened.

The third point is that believers and critics alike underestimate how hard it is to do science. Science is far more complicated than theology. Its esoteric interests, radically counter-intuitive claims and sophisticated forms of inference are difficult to invent, learn and communicate. Science depends on extensive and elaborate social arrangements which are complex and expensive. Its continued existence, at least in the long run, is therefore fragile, certainly in comparison to the continued existence of religion.

Finally, the difference between popular religion and theology suggests that standard comparisons of religion and science are often ill-conceived. Cognitively, science has more in common with theology than it does with religion; both rely on slow, deliberate, reflective thought. Popular religion, on the other hand, is more like a common-sense explanation of the natural world. Those who would criticise either religion or science need to be sure what it is they are attacking. ■

STEVE MCCURRY / MAGNUM PHOTOS

The God hypothesis

The existence, or not, of God is very much a question science can address, argues Victor J. Stenger

THE party line among scientists – believers and non-believers alike – is that science and religion are what Stephen Jay Gould called "non-overlapping magisteria". In 1998 the US National Academy of Sciences issued a statement asserting "Science can say nothing about the supernatural. Whether God exists or not is a question about which science is neutral."

Yet according to a survey the same year, 93 per cent of the members of the academy do not believe in a personal god.

Since about the same percentage of all US citizens say they do believe in a personal god, it makes one wonder what, if not their science, leads the elite of US scientists to differ so dramatically from the general population.

A majority of scientists at all levels do not believe in any god. Yet most are unwilling to challenge the religious beliefs of others. I am a physicist who, along with others dubbed the New Atheists, is willing to challenge religious belief. The gods worshipped by billions either exist or they do not. And those gods, if they exist, must have observable consequences. Thus, the question of their existence is a legitimate scientific issue that has profound import to humanity.

We can consider the existence of God to be a scientific hypothesis and look for the empirical evidence that would follow. Many of the attributes associated with the Judaic-Christian-Islamic God have specific consequences that can be tested empirically. Such a God is supposed to play a central role in the operation of the universe and the lives of humans. As a result, evidence for him should be readily detectable by scientific means.

If a properly controlled experiment were to come up with an observation that cannot be explained by natural means, then science would have to take seriously

RICHARD WILKINSON

the possibility of a world beyond matter.

Such experiments have been attempted. Scientists have empirically tested the efficacy of intercessory prayer – prayers said on behalf of others. These studies, in principle, could have shown scientifically that some god exists. Had they found conclusively, in a double-blind placebo-controlled trial, that intercessory prayers heal the sick, it would have been difficult to find a natural explanation. They did not.

Similar tests have been done on near-death experiences. Some people having an NDE during surgery have reported floating above the operating table and watching everything going on below. Whether this is a real experience or a hallucination can be tested easily by placing a secret message on a high shelf out of sight of the patient and the hospital staff. This has been tried, and no one reporting an NDE has yet to read the message.

Just as science can design experiments to test the existence of God, it can also seek evidence against a god's existence in the world around us. Here we must be clear that we are not talking about evidence against any and all conceivable gods. For example, a deist god that creates the universe and then just leaves it alone would be very hard to falsify. But no one worships a god who does nothing.

If God is the intelligent designer of life on Earth, then we should find evidence for intelligence in observations of the structure of life. We do not. The Intelligent Design movement failed in its effort to prove that the complexity found in some biological systems is irreducible and cannot be explained within Darwinian evolution. Life on Earth looks just as it should look if it arose by natural selection.

> *"The gods worshipped by billions either exist, or they do not; if they exist they must have observable consequences"*

Most religions claim that humans possess immaterial souls that control much of our mental processing. If that were true, we should be able to observe mentally induced phenomena that are independent of brain chemistry. We do not.

If God is the source of morality, then we should find evidence for a supernatural origin in human behaviour. We do not. People of faith behave on average no better, and in some cases behave worse, than people of no faith. History shows that the moral and ethical guides that most of us live by did not originate with the monotheistic religions, as proponents of those religions would have us believe. Instead, moral behaviour appears to have evolved socially.

Again, if God answers prayers, we should see miraculous effects of prayer. With millions of prayers having been said every day for thousands of years, we would expect some to have been answered by now in a verifiable way. They have not.

If God has revealed truths to humanity, then these truths should be testable. Over the millennia many people have reported religious or mystical experiences in which they have communicated with one god or another. By now, we should have seen some confirming evidence for this, such as a verifiable fact that could not have been in the person's head unless it was revealed to them. We have not.

If God is the creator of the universe, then we should find evidence for that in astronomy and physics. We do not. The origin of our universe required no miracles. Furthermore, modern cosmology suggests an eternal "multiverse" in which many other universes come and go.

If humans are a special creation of God, then the universe should be congenial to human life. It is not. Theists claim that the parameters of the universe are fine-tuned for human life. They are not. The universe is not fine-tuned for us. We are fine-tuned to the universe. After evaluating all the evidence, we can conclude that the universe and life look exactly as they would be expected to look if there were no God.

Finally, I would like to comment on the folly of faith. When faith rules over facts, magical thinking becomes deeply ingrained and warps all areas of life. It produces a frame of mind in which concepts are formulated with deep passion but without the slightest attention paid to the evidence. Nowhere is this more evident than in the US today, where Christians who seek to convert the nation into a theocracy dominate the Republican party. Blind faith is no way to run a world. ■

Religion without god

Atheists need to reclaim the useful bits of religion that have been annexed by the godly, Alain de Botton tells Graham Lawton

Your opening gambit in your book, *Religion for Atheists*, is to say, of course religions are not true, and you leave it at that. Does the question not interest you?
No, because I think most of us don't make up our minds in a rational way. You don't say "I'm an atheist because I've looked at all the evidence and this is what I think." Similarly you don't say "I'm religious because I've surveyed all the evidence."

So you don't agree with the "tough-minded critics" who characterise religious people as simpletons and maniacs?
No, not at all. I think that's very much the Dawkins view that essentially religion is a species of stupidity, and this seems to be very narrow-minded.

The central idea of the book is that religion supplies lots of useful and supportive structures that atheists have rejected along with the supernatural. Can you expand on that?
I think the origins of religion are essentially to do with the challenges of living in a community and the challenges of bad stuff happening to us, of which the ultimate is death. Religions are rooted in these needs. They are an attempt to control ourselves, heal ourselves and console ourselves. Some of these manoeuvres are accessible to non-believers and some are not. Belief in the afterlife is simply not there for a non-believer. However, the communal rituals might be utterly accessible to non-believers, and rely in no part on anything supernatural. There are some that can be incorporated into secular life without too much difficulty.

What kind of rituals do you mean?
I suggest various fanciful and not so fanciful interventions. How do you bind a community? It's very simple – you need a host. You need someone who introduces people to each other. The modern world is full of gatherings, but they're not hosted so they remain anonymous. You go to a concert but don't interact with anyone. You go to the pub, but you don't talk to anyone apart from the mates that you walked in with.

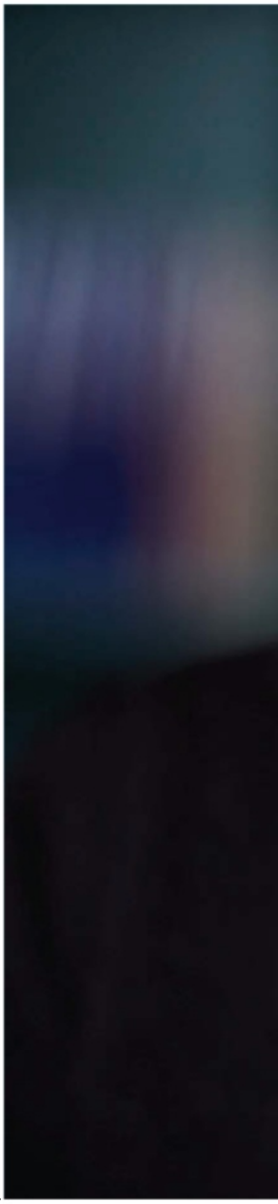
I also look at morality and the need that religions feel to remind people to be good and kind. This is seen as a bit suspicious by secular society. But we are weak-willed. We have aspirations to goodness but just don't manage it. So it seems important to have reminders of these aspirations.

Why have atheists let themselves throw these things away?
I think it's because of a great intellectual honesty: I cannot scientifically appreciate God so I'm going to have to leave all that behind. I'm going to have to give up all those benefits because something doesn't make sense. That's a very honest and very brave, lonely decision.

And yet you say that we have secularised badly. What do you mean?
All sorts of things have become impossible because they seem too religious. There are any number of moments in secular life when atheists say "oh, that's getting a bit religious isn't it". I think we need to relax about approaching some of these areas – they don't belong to religion, religion happened to sit on them. They're for everybody.

Aren't you just reinventing movements that already exist, such as humanism?
Yes, there have been attempts. Part of what has gone wrong is that people have wanted to start new religions, or rival institutions. The point isn't so much to start replacement movements as to integrate practices, attitudes and states of mind into secular life.

PROFILE
Alain de Botton is a writer and television presenter based in London



JOHN REYNOLDS

Not all atheists have reacted well to your suggestions…
I said that atheists should have temples. Immediately 8 million people on Twitter and Facebook decided to let me know what a terrible idea that was. But the core of their objection was not the idea of putting up a building, but the idea that it would be a replacement for a church.

Some atheists argue that we ought to be able to find enough meaning in the grandeur of the natural world. Do you agree?
That's precisely what I think, but I think we need to structure the encounter with that grandeur a little bit better. Essentially, religions are choreographers of spiritual

moments, or psychological moments, and on the whole atheists have not been choreographers at all. I think the genius of religions is that they structure the inner life.

You have this rather wonderful idea of projecting images from the Hubble space telescope in Piccadilly Circus...
Again, it's about structure. We can go to the NASA website, but how often do you go?

In the chapter on religious pessimism – its emphasis on the darker side of existence – you critique the optimism engendered by science and technology. Why is that a bad thing?
The direction of science is towards progress, and so it gives us a feeling that science is about to solve everything. My sense is it will solve a lot of things but the timescale is going to be vast. It could be 400 years, it could be 900 years. The scientific world view doesn't necessarily prepare you for all those things that science is not going to solve in time for you – ultimately, of course, life and death. Whatever the awe-inspiring progress, for the moment at least, we're in just as much trouble as our medieval ancestors.

Religious pessimism is attractive because one of the things that makes life difficult is the assumption that everybody else's life is OK. Pessimism lays out how it is at its worst. No one lives in that bit all the time, but we probably all have to travel there. So it's quite useful to have that as a resource.

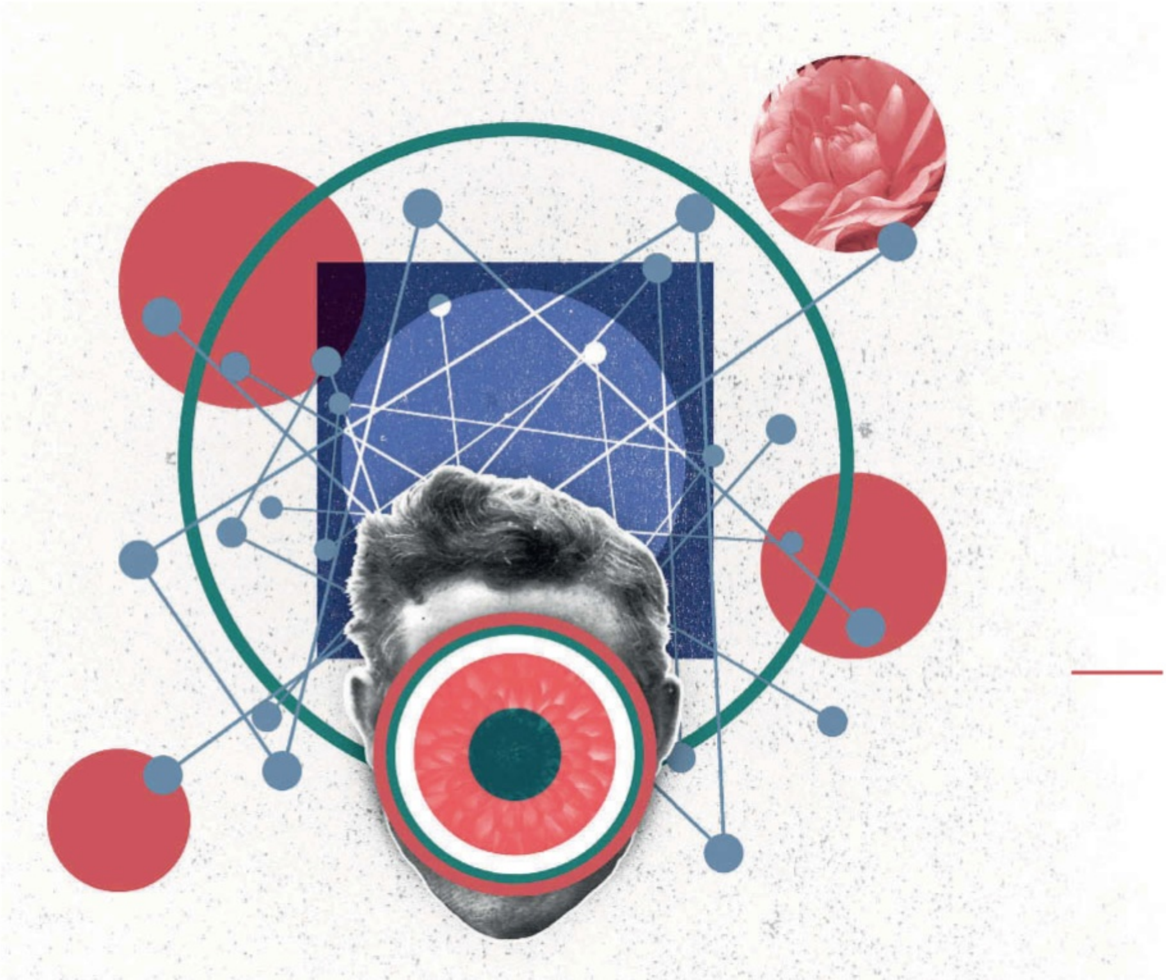
You see this book as the start of something. Where do you go next?
I'm aiming for practical interventions. This is not just theory.

People are looking all the time for things that are missing in the modern world that they might invent some piece of technology to solve. But in the area of how societies are arranged, there is tremendous conservatism. I'm simply trying to get the conversation going in that area.

If there's one thing to take away from the book, it's that even if you give up on the sky daddy, there are still lots of things on the menu that are available to you. I want to make sure atheists are deriving some of the benefits of religion. That's really my ambition. ■

CHAPTER FOUR

CONSCIOUSNESS



THERE are a lot of hard problems in the world, but only one gets to call itself "the hard problem". That is the problem of consciousness – how 1300 grams or so of nerve cells conjures up the seamless kaleidoscope of sensations, thoughts, memories and emotions that occupy every waking moment.

The intractability of this problem prompted British psychologist Stuart Sutherland's notorious 1989 observation: "Consciousness is a fascinating but elusive phenomenon… Nothing worth reading has been written on it."

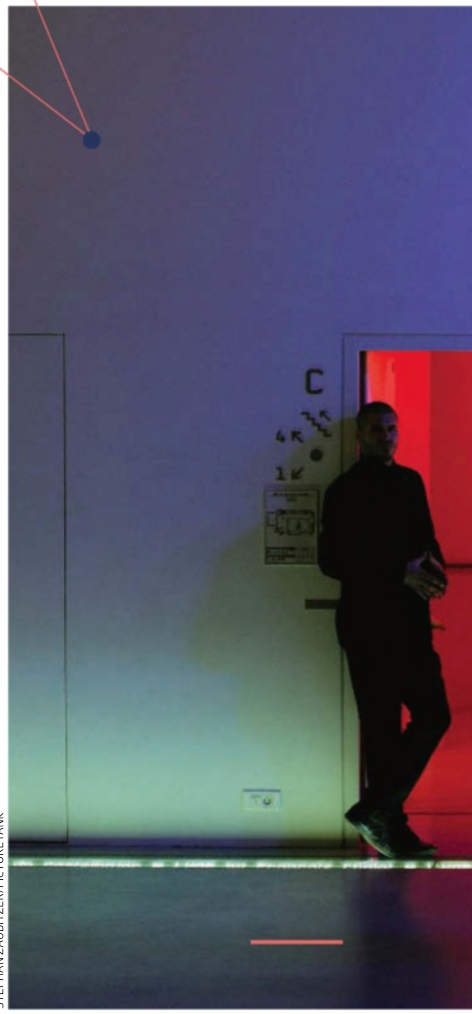
The hard problem remains unsolved. Yet neuroscientists have still made incredible progress understanding consciousness, from the reasons it exists to the problems we have when it doesn't work properly.

Is consciousness still fascinating? Yes. Elusive? Absolutely. But Sutherland's final point no longer stands. Read on…

NATE KITCH

We're no longer forced to speculate about the mind: we can watch it in action, says **Daniel Bor**

This is your brain on consciousness



STEPHAN ZAUBITZER/PICTURETANK

THE first time I saw my father in hospital after his stroke, I was disturbed to find that my strong and confident dad had been replaced by someone confused and childlike. Besides being concerned about whether or not he would recover, I was struck by the profound metaphysical implications of what had just happened.

At the time I was a few weeks away from my final university exams in philosophy and neuroscience, both of which addressed consciousness. In my philosophy lectures I had heard elegant arguments that consciousness is not a physical phenomenon and must be somehow independent of our material, corporeal brains. This idea, most famously articulated by Descartes as dualism, nearly 400 years ago, seemed in stark contrast to the neuroscientific evidence in front of me: my father's consciousness had been maimed by a small blood clot in his brain.

Soon after, I dropped my plans for a PhD in the philosophy of the mind, opting for one on the neuroscience of consciousness instead.

There are certainly questions about our minds that seem more in the realms of philosophy. What is it like to be a bat? Is your experience of seeing the colour red the same as mine, and how do we know for certain that other people are conscious at all? But I would argue that neuroscience, not philosophy, has the best chance of answering these questions.

One area in which we have made great progress is in discovering the physical or neural correlates of consciousness – what consciousness in the brain "looks like", you might say. One way to investigate this question is to see what changes when consciousness is reduced or absent, as happens when people are in a vegetative state, with no sign of awareness.

Brain scans show that such people usually have damage to the thalamus, a relay centre located smack bang in the middle of the brain (see diagram, right). Another common finding is damage to the connections between the thalamus and the prefrontal cortex, a region at the front of the brain, generally responsible for high-level complex thought.

The prefrontal cortex has also been implicated using another technique – scanning the brain while people lose consciousness under general anaesthesia. As awareness fades, a discrete set of regions are deactivated, with the lateral prefrontal cortex the most notable absentee.

Seeing red

Those kinds of investigations have been invaluable for narrowing down the search for the parts of the brain involved in us being awake and aware, but they still don't tell us what happens in the brain when we see the colour red, for example.

Simply getting someone to lie in a brain scanner while they stare at something red won't work, because we know that there is lots of unconscious brain activity caused by visual stimuli – indeed, any sensory stimuli. How can we get round this problem?

One solution is to use stimuli that are just at the threshold of awareness, so they are only sometimes perceived – playing a faint burst of noise, for instance, or flashing a word on a screen almost too briefly to be noticed. If the person does not consciously notice the word flashing up, the only part of the brain that is activated is that which is directly connected to the sense organs concerned, in this case the visual cortex. But if the subject becomes aware of the words or sounds, another set of areas kick into action. These are the lateral prefrontal cortex and the posterior parietal cortex, another region heavily involved in complex, high-level thought, this time at the top of the brain, to the rear.

"IN THEORY WE COULD CALCULATE HOW CONSCIOUS ANYTHING IS, BE IT A HUMAN, RAT OR COMPUTER"

Satisfyingly, while many animals have a thalamus, the two cortical brain areas implicated in consciousness are nothing like as large and well developed in other species as they are in humans. This fits with the common intuition that, while there may be a spectrum of consciousness across the animal kingdom, there is something very special about our own form of it.

In humans the three brain areas implicated in consciousness – the thalamus, lateral prefrontal cortex and posterior parietal cortex – share a distinctive feature: they have more connections to each other, and to elsewhere in the brain, than any other region. With such dense connections, these three regions are best placed to receive, combine and analyse information from the rest of the brain.

Many neuroscientists suspect that it is this drawing together of information that is a hallmark of consciousness. When I talk to a friend in the pub, for instance, I don't experience him as a series of disjointed features, but as a unified whole, combining his appearance with the sound of his voice, knowledge of his name, favourite beer and so on – all amalgamated into a single person-object.

How does the brain knit together all these disparate strands of information from a variety of brain locations? The leading hypothesis is that the relevant neurons start firing in synchrony many times a second, a phenomenon we can see as brainwaves on an electroencephalogram (EEG), whereby electrodes are placed on the scalp. The signature of consciousness seems to be an ultra-fast form of these brainwaves originating in the thalamus and spreading across the cortex.

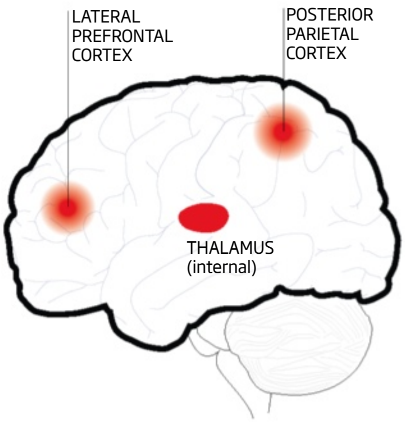
One of the most prominent attempts to turn this experimental data into a theory of consciousness is known as the "global neuronal workspace" model. This suggests that input from our eyes, ears and so on, is first processed unconsciously, primarily in sensory brain regions. It emerges into our conscious awareness only if it ignites activity in the prefrontal and parietal cortices, with these regions connecting through ultra-fast brainwaves.

This model links consciousness with difficult tasks, which often require a drawing together of multiple strands of knowledge. This view fits nicely with the fact that there is high activity in our lateral prefrontal and posterior parietal cortices when we carry out new or complex tasks, while activity in these areas dips when we do repetitive tasks on autopilot, like driving a familiar route.

The main rival to global workspace as a theory of consciousness is a mathematical model called the "information integration theory", which says consciousness is ›

Seats of consciousness

Brain scanning reveals that three areas of the brain play a pivotal role



simply combining data together so that it is more than the sum of its parts. This idea is said to explain why my experience of meeting a friend in the pub, with all senses and knowledge about him wrapped together, feels so much more than the raw sensory information that makes it up.

But the model could be applied equally well to the internet as to a human: its creators make the audacious claim that we should be able to calculate how conscious any particular information-processing network is – be it in the brain of a human, rat or computer. All we need to know is the network's structure, in particular how many nodes it contains and how they are connected together.

Fiendishly hard

Unfortunately the maths involves so many fiendish calculations, which grow exponentially as the number of nodes increases, that our most advanced supercomputers could not perform them in a realistic time frame for even a simple nematode worm with about 300 neurons. The sums may well be simplified in future, however, to make them more practical.

This mathematical theory may seem very different from global neuronal workspace – it ignores the brain's anatomy, for a start – yet encouragingly, both models say consciousness is about combining information, and both focus on the most densely connected parts of the information-processing network. I feel this common ground reflects the significant progress the field is making.

We may not yet have solved the so-called hard problem of consciousness – how a bunch of neurons can generate the experience of seeing the colour red. Yet to me, worrying about the hard problem is just another version of dualism – seeing consciousness as something that is so mysterious it cannot be explained by studying the brain scientifically.

Every time in history we thought there had to be some supernatural cause for a mysterious phenomenon – such as mental illness or even the rising of bread dough – we eventually found the scientific explanation. It seems plausible to me that if we continue to chip away at the "easy problems", we will eventually find there is no hard problem left at all. ■

ALTERED STATES

Sometimes strange states of consciousness can reveal a lot about how we normally construct reality

Liar, liar

Why did you pick that outfit to wear this morning? What made you do your to-do list in that order today? In fact, how did you even end up in that job? You may think you know the reasons, but they could be a work of fiction.

That bizarre conclusion has emerged from studies of people who have had an extreme form of brain surgery - the complete severing of the thick bundle of nerves connecting the two hemispheres of the brain - in an attempt to cure their epilepsy.

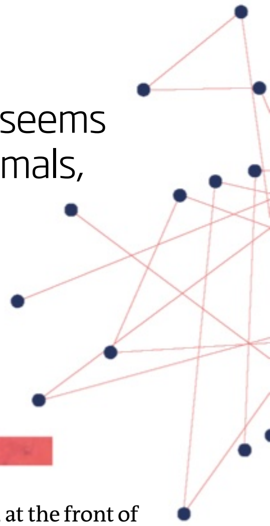
Such people usually seem fine, but tasks that test crosstalk between the hemispheres can catch them out. In one test, people had different images shown to each eye, and had to point to a similar image with the hand on the same side as the eye.

When one person saw a snow scene with his left eye, he chose a picture of a snow shovel with his left hand. But when asked to explain his choice, he had a problem. His left eye and hand's actions were under the control of his right brain, as each brain hemisphere controls the opposite side of the body. But language is controlled by the left brain, which could not access the snowy image "seen" by the right brain. So the subject invented a reason that had nothing to do with snow: the shovel was for cleaning out a chicken coup, he said, as a chicken was the last image seen by his left brain.

Such findings have led to the "interpretive brain" theory, which says that the brain makes up narratives about our actions to help us make sense of the world. Any of us can be tempted into this sort of confabulation. In one study, people who have never had brain surgery were told to choose a picture from a selection, then tricked into thinking they had picked another. When asked for their reasoning, their explanations were convincing - and yet had to be entirely imaginary. Who knows how often our consciousness plays these sorts of tricks on us? Clare Wilson

Being conscious that we are conscious seems to be what sets us apart from other animals, as **Emma Young** discovers

Higher levels



THERE are many ways that human intelligence differs from that of other animals, but one of the most obvious is our level of self-awareness. A pet dog, for instance, is probably aware of many sensations at any given moment: that it is hungry, that it is tired after a long walk, perhaps, and that there is a delicious smell emanating from the kitchen.

Its owner would be aware of all those sensations and yet would have an extra level of thought processes overlaying them. As a human, we can be aware that we are aware of our basic sensory inputs, and that allows us to reflect on the accuracy or validity of our feelings and judgements.

That lets us think: "How tired I am after that long walk, but at least it's that satisfying kind of tiredness you get after exercise. And I'm not too tired to walk to the pub tonight."

This faculty is often referred to as introspection or metacognition. "It's the ability to self-reflect, to know about yourself," says Steve Fleming, who studies consciousness at New York University. "This is something that we think is, if not unique to humans, at least one of the most developed faculties of human psychology."

Fleming dubs this capacity our super-consciousness. "Metacognition seems to be quite core to who we are."

Past research on metacognition has focused on whether it really is unique to humans or whether it is shared to some extent by the more intelligent animals. There have been hints of this capacity in dolphins and monkeys, for instance, although sceptics say there could be other explanations for the results.

Scanning the brains of humans while they carry out metacognitive tasks suggests the seat of this ability lies in our prefrontal cortex, at the front of our heads. But this faculty has been hard to get the measure of. If we ask people how sure they are about their answers in a test, say, the results are muddled by the variation in people's ability to do the test. So are you measuring ability or awareness of that ability?

Fleming's team came up with a crucial extra step. The task they used was a simple visual one, showing people stripy patches in different shades of grey, and asking which had the greatest contrast (see picture, overleaf). After each question subjects had to rate how confident they were that they had chosen the right answer.

Blindsight

Crucially, the contrast of the stripes was adjusted for each person so that, no matter how good their vision, everyone got about 70 per cent of the answers right. That meant that for the confidence ratings, the only variable was people's metacognitive abilities, giving the first demonstration in the lab that this ability varies widely.

As well as doing these tests, the volunteers also had their brain scanned, and this revealed that those with the best metacognitive abilities had more grey matter in an area at the very front of the prefrontal cortex, known as the anterior prefrontal cortex (PFC). This lies just behind the forehead.

"What is it about this region that gives us this ability?" asks Fleming. "Could the fact that it is more developed in humans mean that we have a fundamentally different self-awareness to animals?"

The other classic way of understanding how the brain works is to look what happens when it is not functioning as

NATE KITCH

"THE ABILITY TO SELF-REFLECT IS WHAT GIVES HUMANS THEIR SUPER-CONSCIOUSNESS"

it should. Take "blindsight", a very rare condition usually caused by brain injury. Those affected act as though they are, to all intents and purposes, sightless. But careful testing reveals they can take in some visual information about the world at an unconscious level. When asked to guess what object is in front of them, for instance, they do better than if they had just guessed randomly – insisting all the while that they can see nothing.

Blindsight has always been thought to arise from damage to the visual cortex, at the back of the brain, where information from the optic nerves first arrives. Recent brain imaging studies, however, suggest that the damage also affects connections to the prefrontal cortex, the same region highlighted by Fleming. "That's a pretty big rethink," says Hakwan Lau at Columbia University in New York City, who led the work.

Such a change of heart would sit better with Fleming's work, as blindsight is one of the starkest failures of metacognition it is possible to imagine.

Out of control

Less extreme impairments of metacognition may be involved in other more common disorders, such as schizophrenia, which involves delusions and hallucinations. "Schizophrenics have a problem with that very central metacognition; that I know I'm me and I know what I'm doing," says Janet Metcalfe, also at Columbia University. She has studied the metacognitive abilities of people with schizophrenia using a simple cursor-based computer game. At first the schizophrenia patients were as good at judging how well they performed as the group of healthy control subjects. But when Metcalfe started secretly moving the cursor herself, the control group quickly recognised something strange was going on. People in the schizophrenia group, on the other hand, failed to realise that they were no longer completely responsible for the cursor's movements.

Some people with schizophrenia come to believe that others are controlling their behaviour, claiming, for instance, that a microchip has been implanted inside their head. "If you don't know you're controlling your own behaviour, you could be open to that kind of symptom," says Metcalfe.

As well as potentially helping people with schizophrenia, better understanding of metacognition could improve teaching in schools. Metcalfe has found that children aged from about 7 to 11 are capable of making good metacognitive judgements about how well they know a subject, but may fail to make use of that knowledge.

For instance, such children prefer to continue spending time on a subject they already know rather than moving on. "It would be interesting to try to teach teachers how to use metacognition effectively," says Metcalfe.

It may be possible to improve people's metacognitive abilities, by giving them feedback after the kind of computer tasks used by Fleming. Metcalfe hopes this will help people with schizophrenia. But suppose the rest of us did the same kind of training. Would that give us a supercharged super-consciousness? "If you define consciousness as what it's like to see the colour red, then it's not going to change that," says Fleming. "But if it's being able to accurately reflect on what you see, or whether you just made a good decision, then training could give it a boost." ■

How sure?

In this simple visual test, three screens were briefly flashed up. People were asked whether a patch with the greatest contrast appeared first or last, and then had to say how confident they were about their answer

ALTERED STATES

The twilight zone

Fancy experiencing an altered state of consciousness without resorting to hallucinogenic drugs? Easy. We slip into such a state every night when we sleep, although it's hard to appreciate it at the time because we are, well, unconscious.

But try paying closer attention to the halfway stage as you drop off, known as hypnagogia. "If you are a good observer, you will notice that those spots have a hallucinoid quality to them," says Tore Nielsen, a sleep researcher at Montreal's Sacred Heart Hospital in Canada.

We don't know what causes hypnagogia, but one theory is that some parts of the brain are falling asleep ahead of the rest. "It's known that different parts of the brain tune out at different times," says Nielsen.

Hypnagogia can inspire creativity. Chemist Friedrich August Kekulé had his insight about the ring structure of benzene while half-asleep. Then there was the surrealist Salvador Dali, who tuned in to his creativity by letting himself drop off while suspending a spoon over a metal plate. As he fell asleep, the spoon would crash down, jerking him awake while the dream images were still fresh in his mind.

Hypnagogia is not all fun though. It can sometimes trigger one terrifying kind of sleep paralysis, when the nerve inhibition that normally accompanies our dreams kicks in before someone is fully asleep. "Hypnagogia is largely an uncharted domain," says Nielsen. "We are still developing tools for navigating it."

Nielsen's approach is to track electrical activity in people's brains using EEG while they try to take a nap, under instructions to press a button whenever hypnagogia strikes. "Sometimes you'll have these half-formed hallucinatory images and you're not quite sure whether to call it a dream image. Then you think: 'Maybe it was but now it's too late'," he says. "It's quite a process to teach yourself to identify these ultra-brief images." Liz Else

It feels like you are in the driving seat, but where would you be without your co-pilot, asks **Caroline Williams**

The silent partner

HUMANS are rather proud of their powers of conscious thought – and rightly so. But there is one aspect of our cognitive prowess that rarely gets the credit it deserves: a silent thinking partner that whirrs away in the background. Behold the power of the unconscious mind!

Perhaps this was demonstrated most startlingly with an experiment done in the 1980s by Benjamin Libet at the University of California, San Francisco. People were told to wait a little while and then press a button, and to note the exact time they decided to act on an ultra-precise clock. They also had electrodes placed on their scalp to measure electrical activity in their brain.

This set-up revealed that neuronal activity preceded people's conscious decision to press the button by nearly half a second. More recently a similar experiment placed people in an fMRI scanner instead of hooking them up to electrodes. This found stirrings in the brain's prefrontal cortex up to 10 seconds before someone became aware of having made a decision.

These results are sometimes interpreted as disproving the existence of free will. They could equally well mean that we do have free will, but that it is our unconscious mind that is, in fact, in charge, not the conscious one. Neuroscientist John-Dylan Haynes of Humboldt University in Berlin, Germany, who led the brain scanning study, warns against jumping to this conclusion. "I wouldn't interpret these early [brain] signals as an 'unconscious decision'," he says. "I would think of it more like an unconscious bias of a later decision."

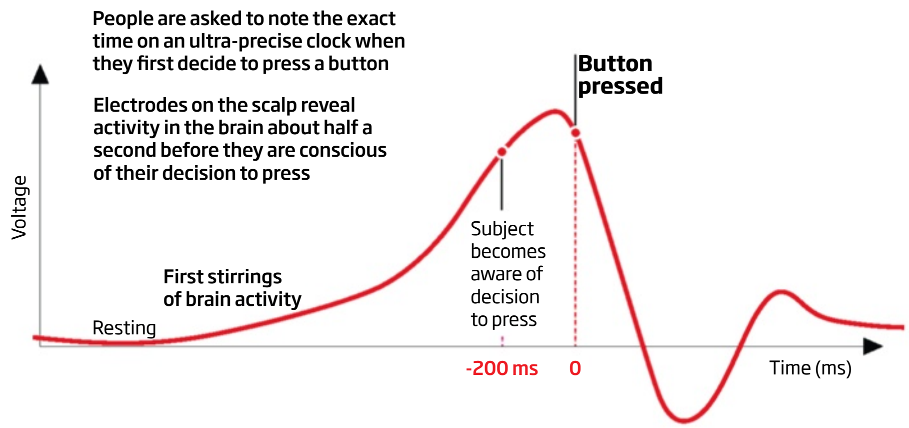
Unfortunately, it is tricky to analyse mental processes that are outside our conscious awareness. Some researchers have even resorted to using ouija boards to try to communicate with people's unconscious. And they have had some success, too.

A more orthodox technique is to use a method called "masking", in which an image is flashed in front of the eyes only to be quickly replaced with another before the first image can consciously register. In this way it has been demonstrated that information shown to the unconscious can spill over into conscious thoughts and decisions. For instance, people shown the masked word "salt" are then more likely to select a related word from a list, like "pepper".

Asking people to choose words from a list might seem a rather artificial test, but such unconscious associations can spill over into life outside the research lab. One study, for instance, showed that people acted more competitively in a game if the pen and paper were taken out of a briefcase rather than a rucksack. Afterwards no one was aware of it affecting their behaviour.

Who's in charge?

This experiment seems to challenge the notion of free will



Make your mind up time

If these ideas are disconcerting, there may be an upside, points out Ap Dijksterhuis of Radboud University Nijmegen in the Netherlands. Our ability to unconsciously process information may help us to make decisions.

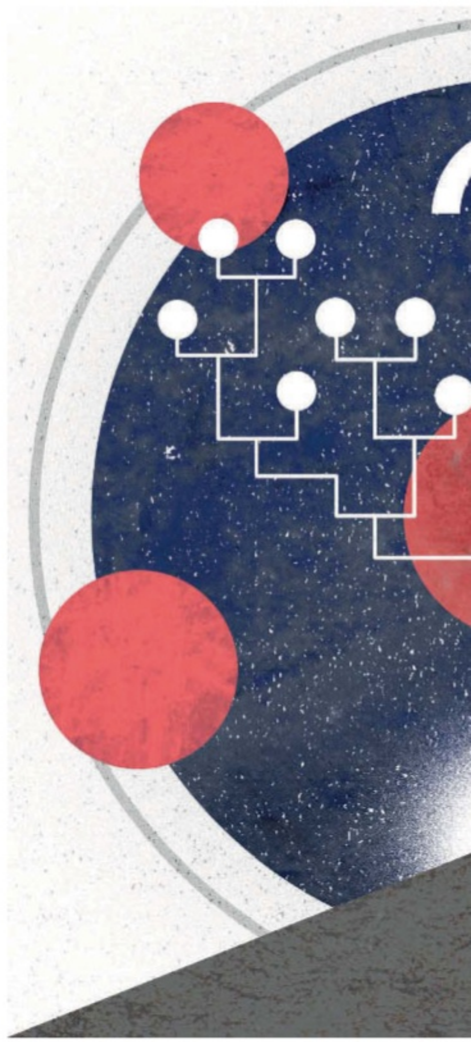
In one study by Dijksterhuis, for instance, people were asked to choose an apartment by one of three methods. These were: making an instant decision; mulling over all the pros and cons for a few minutes; or thinking about an unrelated problem in order to distract them from consciously thinking about the apartments. People chose the objectively best apartment when they used the distraction method. Dijksterhuis thinks that this is because they were unconsciously mulling over the decision while their consciousness was elsewhere.

Dijksterhuis also reckons that unconscious deliberation can explain those "a-ha!" moments when the answer to a problem seems to come from nowhere, as well as times when a searched-for word comes to mind only after we stop trying to recall it. "For all sorts of decisions we are never aware of all the myriads of influencing factors," says Haynes.

Some of these findings have been called into question because other psychologists have been unable to replicate them. Yet there is certainly growing attention paid to the powers of the unconscious. ■

So much time is spent working out what consciousness is, says **Clare Wilson**, that we sometimes neglect an equally important question…

Why be conscious?



IF YOU met a zombie in the street, would you notice? Spotting a horror-film zombie should be easy enough, but the zombies of philosophers' thought experiments are a different matter. They behave almost exactly like everybody else except for one crucial difference: they are not conscious.

Stick this zombie with a pin and it will say "ouch" and recoil. But that's just a reflex – it feels no pain. In fact, this zombie has no subjective sensory experiences, or "qualia", at all. So how do you know for sure that the people around you aren't zombies?

The message you are supposed to take home from this thought experiment is that you have no way of knowing that other people are conscious. Or, in a slightly less radical form, that you can't know if other people experience consciousness in the same way you do. It is a way of exploring one of the most awkward properties of consciousness: its intractable subjectivity.

But there is another – arguably more fruitful – reason for thinking about zombies. What (if any) survival advantage would a conscious human have over a zombie? In other words, what is the function of consciousness? Why did it evolve?

We are used to thinking of physical and mental traits as having adaptive functions. Language, colour vision and upright walking, for example, all have obvious survival advantages. For consciousness, however, this line of inquiry is beset by a problem, points out Geraint Rees at University College London. It is hard to work out what something is for when you are not sure what it is. Equally, it is hard to discover what something is when you don't know what it is for. "That limits our speculation," says Rees.

Despite this catch-22, we have made some inroads into discovering what consciousness is, at least in terms of what we can see going on in the brain using MRI scanners and electrodes on the scalp. One of the leading theories, the global neuronal workspace model, says that sensory stimuli, such as sights and sounds, are initially processed separately and locally at an unconscious level. Only the most salient information emerges into consciousness when it ignites activity in broader networks of neurons across the rest of the brain (see page 52).

Complex tasks

According to this theory, the function of consciousness is to carry out difficult or complex mental tasks – ones that require information from multiple sources to be combined and integrated. Daniel Bor, a neuroscientist at the Sackler Centre for Consciousness Science in Brighton, UK, thinks this is plausible, but has a slightly different take on it. He believes that a key function of consciousness is to combine information in a way that leads to innovation and problem-solving, in particular through a process known as "chunking".

We can usually hold only a few things in working memory at once, but if we clump together related items it is easier to manipulate more concepts simultaneously. "Maybe consciousness is a way of binding components together in order to chunk them," says Bor.

The idea is speculative but there is some supporting evidence. Two of the three areas of the brain seen as the seat of consciousness – the prefrontal and parietal cortices – light up more strongly for mental tasks that require chunking than for anything else.

Another strand of support comes when

"WHAT, IF ANY, SURVIVAL ADVANTAGE WOULD A CONSCIOUS HUMAN HAVE OVER A ZOMBIE"

NATE KITCH

we consider whether any other creatures are conscious: in theory all other animals could be zombies. Yet many people who study consciousness do not see it as an all-or-nothing quality: while other animals may not have the highly developed and special form of consciousness that we have, some species probably have a glimmer of it. And those animals we think of as most likely to be conscious – apes and dolphins, for instance – are also innovative problem-solvers and toolmakers. "I think that's an important clue," says Bor.

These are not the only theories about the function of consciousness. In the 1970s, the idea emerged that it was the need to understand other people's minds that made us aware of our own. "It is more difficult to anticipate the perceptions of others if you cannot perceive your own," says David Barash, a psychologist at the University of Washington in Seattle. That might suggest human consciousness scaled greater heights as our apelike ancestors started living in larger social groups, with the ensuing daily potential for aggression and competition.

It is not the only theory that relates the evolution of consciousness to group living. But for neuroscientist Chris Frith of University College London, the benefits concern cooperation rather than competition. "It's so that we can talk to each other about experiences," he says.

Combined senses

Frith's research group has shown that people make better decisions in laboratory tasks if they are allowed to mull over the pros and cons of the evidence with a partner. That might sound obvious, but it is hard to imagine a zombie being able to do so as it requires reflection and introspection, key traits of consciousness. "We have to be able to reflect upon our experiences before we can talk about them," says Frith.

Geraint Rees, who works with Frith, gives the example of two early humans regarding a distant dust cloud and trying to work out if it signals a herd of buffalo or a pride of lions. The better they are at reflecting on their feelings and judgements, the better will be their collective decision-making about whether to hunt or flee. "If you can combine the forces of your sensory systems, that becomes a useful advantage," says Rees.

Yet Frith thinks a better example of the benefits of consciousness would be the early humans discussing the characteristic flavour of buffalo meat, and thereby deducing where the herd had been grazing.

Of course, consciousness could have evolved for multiple reasons – or perhaps none. Some think that rather than having a survival advantage, it is an "epiphenomenon", simply emerging as an automatic property of intelligence.

Yet that can feel like a cop-out. "My guess is that consciousness, because of its complexity and costliness, in fact conferred adaptive value on its possessors," says Barash, "but I can't think of any way to prove it." ■

ALTERED STATES

Out of hand

In the 1960s film *Dr Strangelove*, the lead character had a bizarre affliction. His right arm seemingly had a mind of its own. Such a condition really does exist, although it is vanishingly rare.

People with so-called anarchic hand syndrome find that their affected limb reaches out and grabs things they have no wish to pick up. They might try restraining it with their other hand, and if that doesn't work, "they sometimes come to the surgery with their hand tied up", says Sergio Della Sala, a neuroscientist at the University of Edinburgh, UK, who studies the condition.

The cause is injury to the brain, usually in a region known as the supplementary motor area (SMA). Work on monkeys has shown that another part of the brain, the premotor cortex, generates some of our actions unconsciously in response to things we see around us. The SMA then kicks in to allow the movement or stop it, but damage to the SMA can wreck this control – hence the anarchic hand, acting on every visual cue.

A few people are unfortunate enough to have damage to the SMA on both sides of the brain, and experience both hands acting outside their control. They are at the mercy of environmental triggers, says Della Sala.

The system sounds like the very opposite of free will – Della Sala calls it "free won't". The findings suggest that, while it feels like our actions are always under our conscious control, in fact there is a lot of unconscious decision-making going on too.

If that sounds implausible, have you ever been driving somewhere on a day off and found yourself heading towards the office the moment you hit part of your normal route to work? That's your premotor cortex responding to an environmental cue right there.

Clare Wilson

I, robot

We will only understand consciousness once we can give it to machines, says **Celeste Biever**

FROM C-3PO of *Star Wars* to Wall-E the sentient garbage collector, the prevalence of conscious machines in the stories we tell seems to reflect humanity's deep desire to turn creator and design an artificial intelligence.

It might seem as if we stand little chance of making an artificial consciousness when the natural variety remains such an enigma. But in fact the quest for machine consciousness may be key to solving the mystery of human consciousness, as even scientists outside AI research are starting to acknowledge. "The best way of understanding something is to try and replicate it," says psychologist Kevin O'Regan of Descartes University in Paris, France. "So if you want to understand what consciousness is, well make a machine that's conscious."

That may sound fanciful, but AI research has already sparked one of the leading theories of consciousness to date – the global neuronal workspace model. It derives from attempts in the 1970s to develop computer speech recognition. One approach was to try to identify short sounds, roughly equivalent to individual letters, which had to be strung into syllables, then into words and sentences.

Because of the ambiguities at each step of this process – think of the many possible meanings of the sound "to" for instance – exploring all the possibilities in turn would have taken far too long. So multiple programs worked at different stages of the problem in parallel, sharing the results likely to be of interest to others through a central database known as the blackboard.

The resulting Hearsay II system was 90 per cent accurate, as long it stuck to a vocabulary of 1000 words. It was eventually overtaken by other software, but not before it had come to the attention of philosopher Bernard Baars, who wondered whether our own brains might have a similar architecture.

Baars, now at The Neurosciences Institute in La Jolla, California, saw consciousness in the role of the blackboard, although he called it the brain's global workspace. Baars proposed that incoming sensory information and other low-level thought processes initially stay in the unconscious. Only when information is salient enough to enter the global workspace do we become aware of it in the form of a conscious "broadcast" to the whole brain. Since Baars proposed this idea in 1983, numerous strands of supporting evidence have accumulated, including that derived from scanning the brains of people under anaesthesia.

Whereas Baars stumbled on the AI work that informed his theory, some computer scientists are now deliberately trying to copy the human brain. Take a software bot called LIDA, which stands for learning intelligent distribution agent. LIDA has unconscious and conscious software routines working in parallel, designed as a test of global workspace principles. But in this case the term "conscious" does not mean that the program is sentient, just that it broadcasts the most important results across all subroutines.

Nitty-gritty

The much-hyped Human Brain Project, based in Switzerland, aims to build a functioning software simulation of the entire human brain on a supercomputer within 10 years. So far the team has managed to model a small chunk of rat brain, but in February 2013 the project won a €1 billion grant, which they reckon will take them to simulating a whole human brain.

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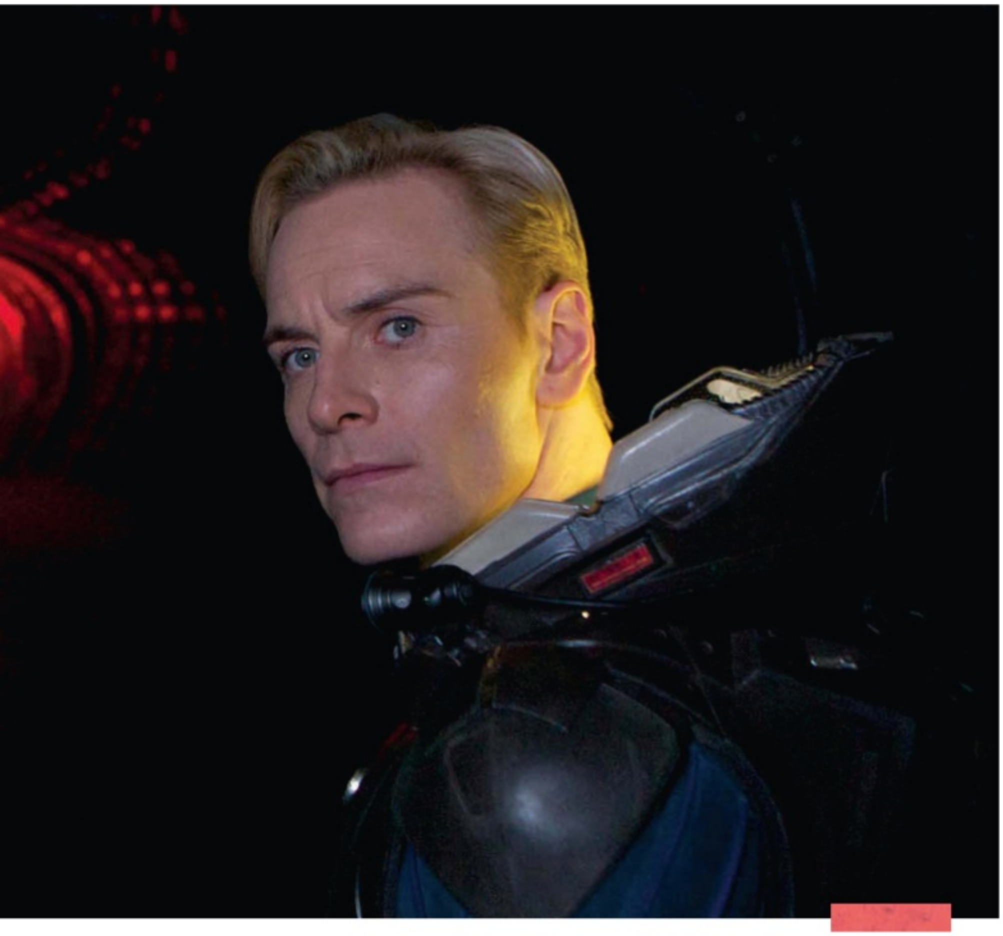
But copying the brain's architecture misses the point, O'Regan thinks. "How the brain is organised isn't the interesting question," he says. "The interesting question is, why do we feel?" In other words, how can electricity moving through neurons create the subjective feeling of pain, or the colour red? "It's not just that we know we are in pain, there is the real, nitty-gritty feel," he says.

Trying to create a machine that experiences pain or colours in the same way that we do might require a radical rethink. Pentti Haikonen, an electrical engineer and philosopher at the University of Illinois in Springfield, believes that we will never create a feeling machine using software. Software is a language, he says, and so requires extra information to be interpreted. If you don't speak English, the words "pain" or "red", for instance, are meaningless. But if you see the colour red, that has meaning no matter what your language.

How could we ever be sure that an android is conscious?



Most computers and robots created so far run on software. Even if they connect to a physical device, like a microphone, the input has to be translated into strings of 1s and 0s before it can be processed. "Numbers do not feel like anything and do not appear as red," says Haikonen. "That is where everything is lost."

Not so for Haikonen's robot. His machine, called XCR for experimental cognitive robot, stores and manipulates incoming sensory information, not via software, but through physical objects – in this case wires, resistors and diodes. "Red is red, pain is pain without any interpretation," says Haikonen. "They are direct experiences to the brain."

XCR has been built so that, if hit with sufficient force, the resulting electrical signal makes it reverse direction – an avoidance response corresponding to pain, Haikonen says. The robot is also capable of a primitive kind of learning. If, when it is hit, it is holding a blue object, say, the signal from its blue-detecting photodiode permanently opens a switch. From now on, the robot associates the colour blue with pain and reverses away.

"IT'S HARD NOT TO FEEL SYMPATHY AS THE ROBOT IS WHACKED WITH A STICK. 'ME HURT,' IT INTONES"

Watch the robot in training and it is hard not to feel sympathy as it is whacked with a stick. "Bad," it intones. "Me hurt, blue bad." The next time Haikonen tries to push the robot towards a blue object, it backs away. "Blue, bad."

Does Haikonen ever feel guilty about hitting his robot? "Now that you put it that way," he says, "I may feel a little bad."

As robot achievements go, learning to avoid a blue object is no big deal: conventional software-based robots can do it with ease. But the fact that XCR bypasses software, storing sensory information directly in its hardware, takes it the first step down the road to awareness, claims Haikonen. "The contents of the consciousness is limited," he says, "but the phenomenon is there."

Brain in a vat

It's a claim that Haikonen makes very cautiously, and one that has not yet convinced many others in the field. "I would hesitate to call something conscious that had such a limited repertoire of responses," says Murray Shanahan, who studies machine consciousness at Imperial College London. Still, it's a new approach, and the first time that such a claim has been made by any serious AI researcher.

If Haikonen is right, and we can't create a conscious machine based on software, then software simulations of the human brain will never be sentient. Nor will the internet, no matter how big it gets. But a real brain in a vat wired up to a supercomputer simulation – a classic thought experiment from philosophy – could be conscious. Haikonen does not say awareness needs a physical body, just a physical brain.

Whether artificial brains of the future run on software or hardware, how would we know if they do achieve sentience? Self-awareness is, by definition, a highly subjective quality.

The answer is simple, says O'Regan. Once they behave in the same way we do, we will simply have to assume they are as conscious as we are.

If that sounds preposterous, don't forget, it's the same assumption we make routinely about our fellow humans every day of our lives.

After all, if you somehow got talking to an alien, and you had a similar conversation to one you might have with a person, "you would probably agree that it was conscious – even if it turned out there was cottage cheese inside its brain", says O'Regan. "The underpinnings of his behaviours are irrelevant."

"When you say that I am conscious, that's what makes me conscious," says O'Regan. ■

The universe is full of wonders, but surely nothing is as wonderful as the peculiar configuration of matter and energy we call life. As far as we know, Earth is the only planet where it exists, but we are surely not alone. Life seems to have got started almost as soon as the Earth was habitable, and there's little reason to think the same won't happen on other suitable planets – of which there are billions in our solar system alone. So where are the aliens?

There are also plenty of things we don't understand about life in our own backyard. One is its sheer diversity. We have identified around 2 million species and there may be another 20 or 30 million to discover. Where do they all come from?

Now is also a good time to take stock. We think that human activities are causing a mass extinction, so what does the future of life look like?

Inevitable, fluke, or both?

In theory, life ought to arise wherever conditions are right. But that doesn't mean the universe is teeming with creatures like us, says Nick Lane

FOR four years, the Kepler space telescope scoured the sky for Earth-like planets around other stars. When its mission ended in August 2013, it had found so many that NASA came to a startling conclusion: our galaxy is teeming with planets capable of hosting life. There are perhaps 40 billion of them, 11 billion of which are small rocky worlds orbiting sunlike stars at a distance where liquid water may exist.

These discoveries are bringing an old paradox back into focus. As physicist Enrico Fermi asked in 1950, if there are many suitable homes for life out there and alien life forms are common, where are they all? More than half a century of searching for extraterrestrial intelligence has so far come up empty-handed.

Of course, the universe is a very big place. Even Frank Drake's famously optimistic "equation" for life's probability suggests that we will be lucky to stumble across intelligent aliens: they may be out there, but we'll never know it. That answer satisfies no one, however.

There are deeper explanations. Perhaps ›

alien civilisations appear and disappear in a galactic blink of an eye, destroying themselves long before they become capable of colonising new planets. Or maybe life very rarely gets started even when conditions are perfect.

If we cannot answer these kinds of questions by looking out, might it be possible to get some clues by looking in? Life arose only once on Earth, and if a sample of one were all we had to go on, no grand conclusions could be drawn. But there is more than that. Looking at a vital ingredient for life – energy – suggests that simple life is common throughout the universe, but it does not inevitably evolve into more complex forms such as animals. I might be wrong, but if I'm right, the immense delay between life first appearing on Earth and the emergence of complex life points to another, very different explanation for why we have yet to discover aliens.

Living things consume an extraordinary amount of energy, just to go on living. The food we eat gets turned into the fuel that powers all living cells, called ATP. This fuel is continually recycled: over the course of a day, humans each churn through 70 to 100 kilograms of the stuff. This huge quantity of fuel is made by enzymes, biological catalysts fine-tuned over aeons to extract every last joule of usable energy from reactions.

The enzymes that powered the first life cannot have been as efficient, and the first cells must have needed a lot more energy to grow and divide – probably thousands or millions of times as much energy as modern cells. The same must be true throughout the universe.

This phenomenal energy requirement is often left out of considerations of life's origin. What could the primordial energy source have been here on Earth? Old ideas of lightning or ultraviolet radiation just don't pass muster. Aside from the fact that no living cells obtain their energy this way, there is nothing to focus the energy in one place. The first life could not go looking for energy, so it must have arisen where energy was plentiful.

Today, most life ultimately gets its energy from the sun via photosynthesis by plants. But photosynthesis is an enormously complex process and probably didn't power the first life. So what did?

Reconstructing the history of life by comparing the genomes of simple cells is fraught with problems. Nevertheless, such studies all point in the same direction. The earliest cells seem to have gained their energy and carbon from the gases hydrogen and carbon dioxide. The reaction of H_2 with CO_2 produces organic molecules directly, and releases energy. That is important, because it is not enough to form simple molecules: it takes buckets of energy to join them up into the long chains that are the building blocks of life.

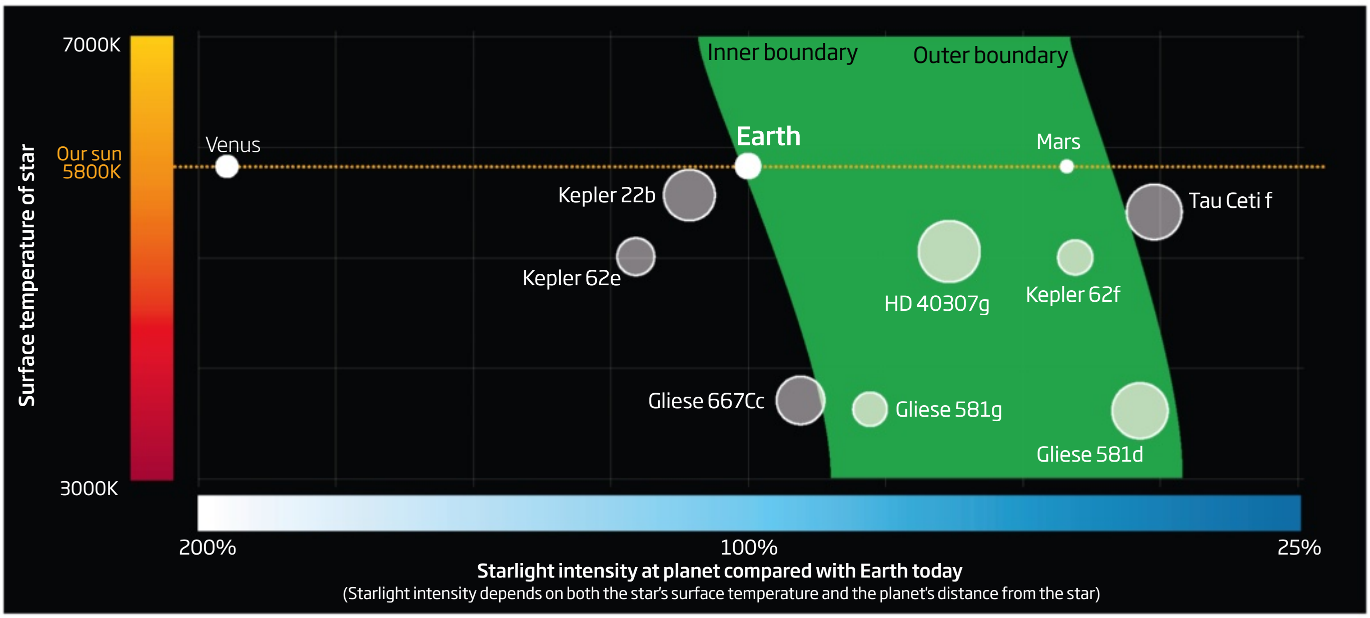
A second clue to how the first life got its energy comes from the energy-harvesting mechanism found in all known life forms. This mechanism was so unexpected that there were two decades of heated altercations after it was proposed by British biochemist Peter Mitchell in 1961.

Universal force field

Mitchell suggested that cells are powered not by chemical reactions, but by a kind of electricity, specifically by a difference in the concentration of protons (the charged nuclei of hydrogen atoms) across a membrane. Because protons have a positive charge, the concentration difference produces an electrical potential difference between the two sides of the membrane of about 150 millivolts. It might not sound like much, but because it operates over only 5 millionths of a millimetre, the field strength over that tiny distance is enormous, around 30 million volts per metre. That's equivalent to a bolt of lightning.

The habitable zone

A star's habitable zone is the region around it in which an Earth-like planet can have liquid water. The search for extrasolar planets is in its infancy but we have already found a number in, or close to, the habitable zones of their stars



D. KELLEY/UNIVERSITY OF WASHINGTON

Alkaline thermal vents may have incubated the first life

Mitchell called this electrical driving force the proton-motive force. It sounds like a term from *Star Wars*, and that's not inappropriate. Essentially, all cells are powered by a force field as universal to life on Earth as the genetic code. This tremendous electrical potential can be tapped directly, to drive the motion of flagella, for instance, or harnessed to make the energy-rich fuel ATP.

However, the way in which this force field is generated and tapped is extremely complex. The enzyme that makes ATP is a rotating motor powered by the inward flow of protons. Another protein that helps to generate the membrane potential, NADH dehydrogenase, is like a steam engine, with a moving piston for pumping out protons. These amazing nanoscopic machines must be the product of prolonged natural selection. They could not have powered life from the beginning, which leaves us with a paradox.

Life guzzles energy, and inefficient primordial cells must have required much more energy, not less. These vast amounts of energy are most likely to have derived from a proton gradient, because the universality of this mechanism means it evolved early on. But how did early life manage something that today requires very sophisticated machinery?

There is a simple way to get huge amounts of energy this way. What's more, the context makes me think that it really wasn't that difficult for life to arise in the first place.

The answer I favour was proposed 20 years ago by the geologist Michael Russell, now at NASA's Jet Propulsion Laboratory in Pasadena, California, who had been studying deep-sea hydrothermal vents. Say "deep-sea vent" and many people think of dramatic black smokers surrounded by giant tube worms. Russell had something much more modest in mind: alkaline hydrothermal vents. These are not volcanic at all, and don't smoke. They are formed as seawater percolates down into the electron-dense rocks found in the Earth's mantle, such as the iron-magnesium mineral olivine.

Olivine and water react to form serpentinite in a process that expands and cracks the rock, allowing in more water and perpetuating the reaction. Serpentinisation produces alkaline fluids rich in hydrogen gas, and the heat it releases drives these fluids back up to the ocean floor. When they come into contact with cooler ocean waters, the minerals precipitate out, forming towering vents up to 60 metres tall. Such vents, Russell realised, provide everything needed to incubate life.
Or rather they did, four billion years ago.

Back then, there was very little, if any, oxygen, so the oceans were rich in dissolved iron. There was probably a lot more CO_2 than there is today, which meant that the oceans were mildly acidic – that is, they had an excess of protons.

Just think what happens in a situation like this. Inside the porous vents, there are tiny, interconnected cell-like spaces enclosed by flimsy mineral walls. These walls contain the same catalysts – notably various iron, nickel and molybdenum sulphides – used by cells today (albeit embedded in proteins) to catalyse the conversion of CO_2 into organic molecules.

Fluids rich in hydrogen percolate through this labyrinth of catalytic micropores. Normally, it is hard to get CO_2 and H_2 to react: efforts to capture CO_2 to reduce global warming face exactly this problem. Catalysts alone may not be enough. But living cells don't capture carbon using catalysts alone – they use proton gradients to drive the reaction. And between a vent's alkaline fluids and acidic water there is a natural proton gradient.

Could this natural proton-motive force have driven the formation of organic molecules? I'm working on exactly that question. It is too early to say for sure, but the early signs are that the answer is yes.

What would that solve? A great deal. Once the barrier to the reaction between CO_2 and H_2 is down, the reaction can proceed apace. Remarkably, under conditions typical of alkaline hydrothermal vents, the combining of H_2 and CO_2 to produce the molecules found in living cells – amino acids, lipids, sugars and nucleobases – actually releases energy.

That means that far from being some mysterious exception to the second law of

"EXISTING LIFE FORMS GUZZLE ENERGY, AND INEFFICIENT PRIMORDIAL CELLS MUST HAVE REQUIRED MUCH MORE ENERGY. HOW DID THEY MANAGE?"

thermodynamics, from this point of view, life is in fact driven by it. It is an inevitable consequence of a planetary imbalance, in which electron-rich rocks are separated from electron-poor, acidic oceans by a thin crust, perforated by vent systems that focus this electrochemical driving force into cell-like systems. The planet can be seen as a giant battery; the cell is a tiny battery built on basically the same principles.

I'm the first to admit that there are many gaps to fill in, many steps between an electrochemical reactor that produces organic molecules and a living, breathing cell. But consider the bigger picture for a moment. The origin of life needs a very short shopping list: rock, water and CO_2.

Water and olivine are among the most abundant substances in the universe. Many planetary atmospheres in the solar system are rich in CO_2, suggesting that it is common too. Serpentinisation is a spontaneous reaction, and should happen on a large scale on any wet, rocky planet. From this perspective, the universe should be teeming with simple cells – life may indeed be inevitable whenever the conditions are right. It's hardly surprising that life on Earth seems to have begun almost as soon as it could.

Then what happens? It is generally assumed that once simple life has emerged, it gradually evolves into more complex forms, given the right conditions. But that's not what happened on Earth. After simple cells first appeared, there was an extraordinarily long delay – nearly half the lifetime of the planet – before complex ones evolved. What's more, simple cells gave rise to complex ones just once in four billion years of evolution: a shockingly rare anomaly, suggestive of a freak accident.

If simple cells had slowly evolved into more complex ones over billions of years, all kinds of intermediate cells would have existed and some still should. But there are none. Instead, there is a great gulf. On the one hand, there are the prokaryotes (bacteria and archaea), tiny in both their cell volume and genome size. They are streamlined by selection, pared down to a minimum: fighter jets among cells. On the other, there are the vast and unwieldy eukaryotic cells, more like aircraft carriers than fighter jets. A typical single-celled eukaryote is about 15,000 times larger than a bacterium, with a genome to match.

The great divide

All the complex life on Earth – animals, plants, fungi and so on – are eukaryotes, and they all evolved from the same ancestor. So without the one-off event that produced the ancestor of eukaryotic cells, there would have been no plants and fish, no dinosaurs and apes. Simple cells just don't have the right cellular architecture to evolve into more complex forms.

Why not? I recently explored this issue with the pioneering cell biologist Bill Martin of Heinrich Heine University in Düsseldorf, Germany. Drawing on data about the metabolic rates and genome sizes of various cells, we calculated how much energy would be available to simple cells as they grew bigger.

What we discovered is that there is an extraordinary energetic penalty for growing larger. If you were to expand a bacterium up to eukaryotic proportions, it would have tens of thousands of times less energy available per gene than an equivalent eukaryote. And cells need lots of energy per gene, because making a protein from a gene is an energy-intensive process. Most of a cell's energy goes into making proteins.

At first sight, the idea that bacteria have nothing to gain by growing larger would seem to be undermined by the fact that there are some giant bacteria bigger than many complex cells, notably *Epulopiscium*, which thrives in the gut of the surgeonfish. Yet *Epulopiscium* has up to 200,000 copies of its complete genome. Taking all these multiple genomes into consideration, the energy available for each copy of any gene is almost exactly the same as for normal bacteria, despite the vast total amount of DNA. They are perhaps best seen as consortia of cells that have fused together into one, rather than as giant cells.

So why do giant bacteria need so many copies of their genome? Recall that cells harvest energy from the force field across their membranes, and that this membrane potential equates to a bolt of lightning. Cells get it wrong at their peril. If they lose control of the membrane potential, they die. Nearly 20 years ago, biochemist John Allen, now at Queen Mary, University of London, suggested that genomes are essential for controlling the membrane potential, by controlling protein production. These genomes need to be near the membrane they control so they can respond swiftly to local changes in conditions. Allen and others have amassed a good deal of evidence that this is true for eukaryotes, and there are good reasons to think it applies to simple cells, too.

"FAR FROM BEING SOME MYSTERIOUS EXCEPTION TO THERMODYNAMICS, FROM THIS POINT OF VIEW LIFE IS IN FACT DRIVEN BY THERMODYNAMICS"

"WHEN WE LOOK AT WHAT BACTERIA NEED TO BECOME MORE COMPLEX, WE SEE THEY OCCUPY A DEEP CANYON IN THE ENERGY LANDSCAPE"

So the problem that simple cells face is this. To grow larger and more complex, they have to generate more energy. The only way they can do this is to expand the area of the membrane they use to harvest energy. To maintain control of the membrane potential as the area of the membrane expands, though, they have to make extra copies of their entire genome – which means they don't actually gain any energy per gene copy.

Put another way, the more genes that simple cells acquire, the less they can do with them. And a genome full of genes that can't be used is no advantage. This is a tremendous barrier to growing more complex, because making a fish or a tree requires thousands more genes than bacteria possess.

So how did eukaryotes get around this problem? By acquiring mitochondria.

About 2 billion years ago, one simple cell somehow ended up inside another. The identity of the host cell isn't clear, but we know it acquired a bacterium, which began to divide within it. These cells within cells competed for succession; those that replicated fastest, without losing their capacity to generate energy, were likely to be better represented in the next generation.

And so on, generation after generation, these "endosymbiotic" bacteria evolved into tiny power generators, containing both the membrane needed to make ATP and the genome needed to control membrane potential. Crucially, though, along the way they were stripped down to a bare minimum. Anything unnecessary has gone, in true bacterial style. Mitochondria originally had a genome of perhaps 3000 genes; nowadays they have just 40 or so genes left.

For the host cell, it was a different matter. As the mitochondrial genome shrank, the amount of energy available per host-gene copy increased and its genome could expand. Awash in ATP, served by squadrons of mitochondria, it was free to accumulate DNA and grow larger. You can think of mitochondria as a fleet of helicopters that "carry" the DNA in the nucleus of the cell. As mitochondrial genomes were stripped of their own unnecessary DNA, they became lighter and could each lift a heavier load, allowing the nuclear genome to grow ever larger.

These huge genomes provided the genetic raw material that led to the evolution of complex life. Mitochondria did not prescribe complexity, but they permitted it. It's hard to imagine any other way of getting around the energy problem – and we know it happened just once on Earth because all eukaryotes descend from a common ancestor.

Freak of nature

The emergence of complex life, then, seems to hinge on a single fluke event – the acquisition of one simple cell by another. Such associations may be common among complex cells, but they are extremely rare in simple ones. And the outcome was by no means certain: the two intimate partners went through a lot of difficult co-adaptation before their descendants could flourish.

This does not bode well for the prospects of finding intelligent aliens. It means there is no inevitable evolutionary trajectory from simple to complex life. Never-ending natural selection, operating on infinite populations of bacteria over billions of years, may never give rise to complexity. Bacteria simply do not have the right architecture. They are not energetically limited as they are – the problem only becomes visible when we look at what it would take for their volume and genome size to expand. Only then can we see that bacteria occupy a deep canyon in an energy landscape, from which they are unable to escape.

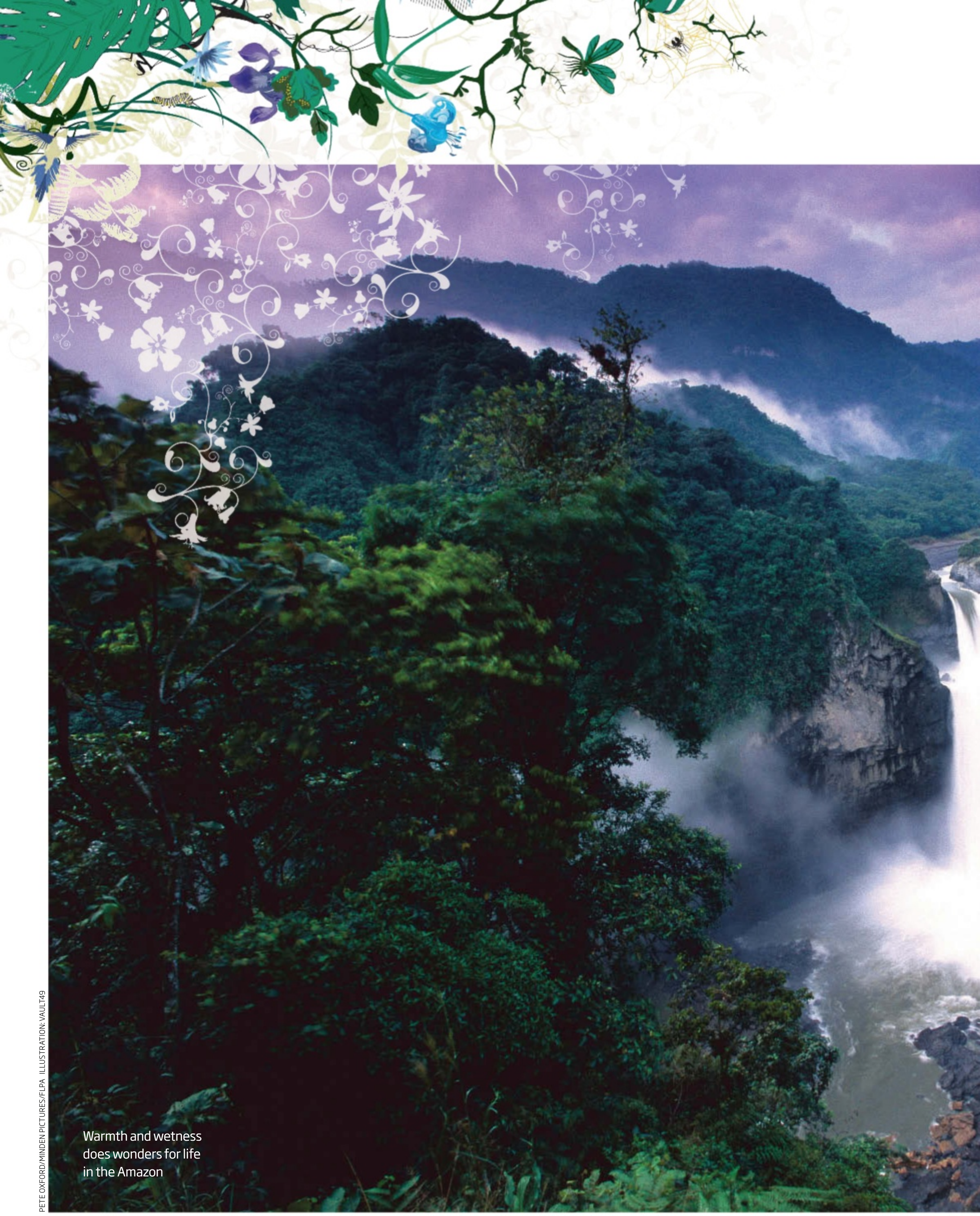
So what chance life? It would be surprising if simple life were not common throughout the universe. Simple cells are built from the most ubiquitous of materials – water, rock and CO_2 – and they are thermodynamically close to inevitable. Their early appearance on Earth, far from being a statistical quirk, is exactly what we would expect.

The optimistic assumption of the Drake equation was that on planets where life emerged, 1 per cent gave rise to intelligent life. But if I'm right, complex life is not at all inevitable. It arose here just once in four billion years thanks to a rare, random event. There's every reason to think that a similar freak accident would be needed anywhere else in the universe too. Nothing else could break through the energetic barrier to complexity.

This line of reasoning suggests that while Earth-like planets may teem with life, very few ever give rise to complex cells. That means there are very few opportunities for plants and animals to evolve, let alone intelligent life. So even if we discover that simple cells evolved on Mars, too, it won't tell us much about how common animal life is elsewhere in the universe.

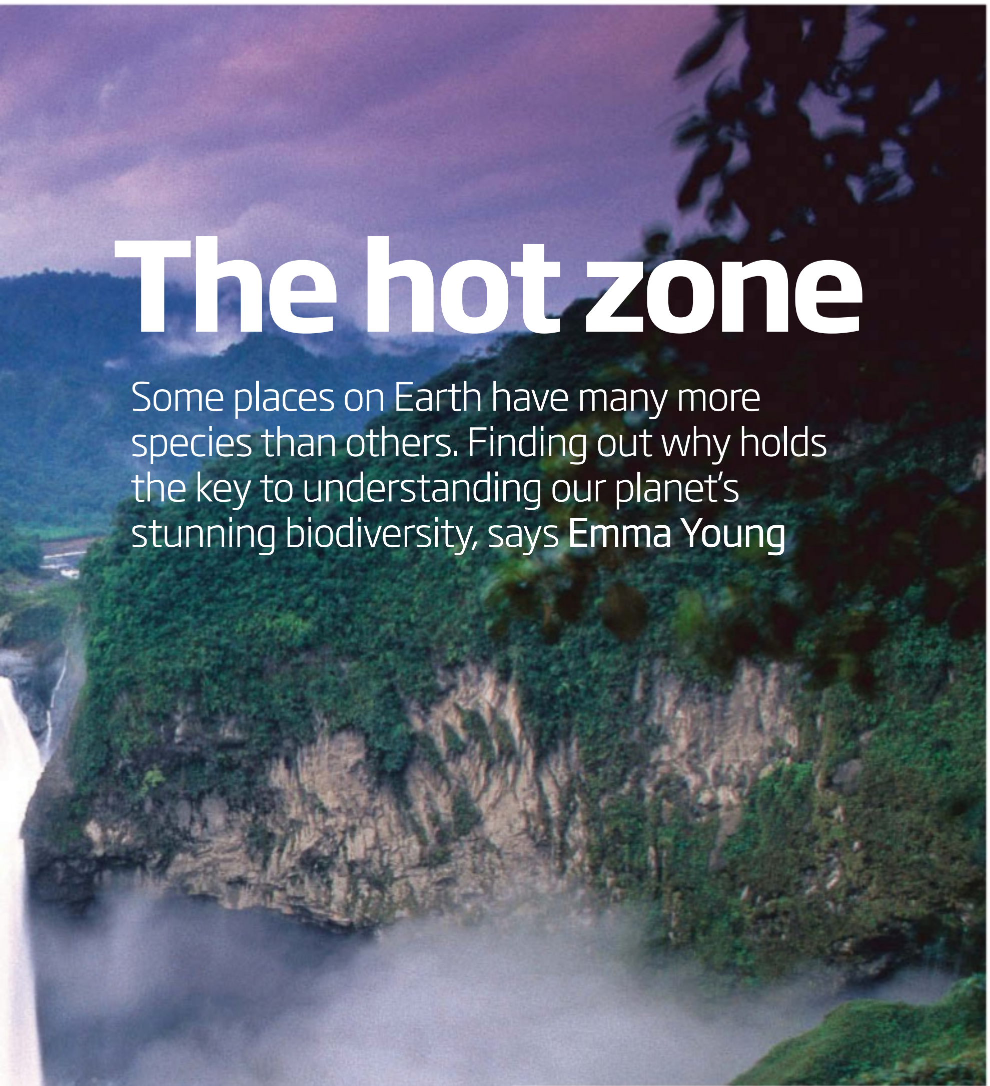
All this might help to explain why we've never found any sign of aliens. Of course, some of the other explanations that have been proposed, such as life on other planets usually being wiped out by catastrophic events such as gamma-ray bursts long before smart aliens get a chance to evolve, could well be true too. If so, there may be very few other intelligent beings in the galaxy.

Then, again, perhaps some just happen to live in our neighbourhood. If we do ever meet them, there's one thing I would bet on: they will have mitochondria too. ■



PETE OXFORD/MINDEN PICTURES/FLPA ILLUSTRATION: VAULT49

Warmth and wetness does wonders for life in the Amazon



The hot zone

Some places on Earth have many more species than others. Finding out why holds the key to understanding our planet's stunning biodiversity, says **Emma Young**

DEEP in the western Amazon lies the Yasuni National Park. Packed within an average hectare of this dense, steamy Ecuadorian rainforest are more species of tree than are native to the US and Canada combined, as well as 150 types of amphibian and an estimated 100,000 insect species. According to recent research there are more different life forms in Yasuni than anywhere else in South America. "It's hard to get very far, because every few minutes you see or hear something new," says Matt Finer, who led the work as staff ecologist at Save America's Forests. Yasuni may well be the most biodiverse place in the world.

If Yasuni does indeed hold this title, its tropical location will come as no surprise to biologists. The tropics boast more than 10 times as many species of animal and plant as the Arctic, with diversity decreasing steadily as you approach the poles. This gradient holds true for both land and the abyssal ocean depths. The big question, though, is why? What is it about the tropics that so fosters biodiversity? It is a mystery that has puzzled biologists for decades. Yasuni might help us find an answer.

According to one classic theory, the reason is simply that there is more habitable space around the equator than at the poles. On the face of it, this seems to make sense. The tropics encompass an area nearly five times the size of the Earth's polar regions, and there is some evidence that habitable space

"Speciation rates could be particularly high at the tropics, making them a cradle of biodiversity"

is correlated with the number of species on land. Research in the ocean tells a different story, however.

David Jablonski at the University of Chicago and his colleagues are involved in a long-term study of living and fossil marine bivalves, a group that includes oysters, mussels, cockles, clams and scallops. Looking at present-day biodiversity patterns in 4000 bivalve species, they have found no relationship between habitable area – in this case, continental shelf – and the number of bivalve species. "Habitable area just doesn't explain marine diversity gradients," Jablonski says.

Perhaps biodiversity at sea and on land are governed by different rules. The traditional explanation for patterns of marine biodiversity is known as Rapoport's rule. The idea here is that ocean-dwelling species in the tropics are very sensitive to temperature, so are restricted to small ranges where the water is just right, whereas species in cooler waters can tolerate a broader range of temperatures, and so spread out. This could explain why large numbers of species are packed together in the tropics, but it doesn't ›

Hotspots and high drama

Proximity to the equator may be enough to explain some biodiversity hotspots, but other factors can also lead to an explosion of species. Prominent among them are dramatic, environment-changing events.

For example, a spate of asteroid impacts could have laid the foundation for the explosion of new life forms during the Ordovician period, which began 489 million years ago. Birger Schmitz, a geologist at the University of Lund in Sweden, suspects the bombardment created localised extinctions and new habitats, which life then evolved to fill.

A similar event is thought to have led to the extinction of 85 per cent of species, including the dinosaurs, at the end of the Cretaceous period 65 million years ago. This created an immense evolutionary space for other species to expand into.

The most rapid speciation event of any plant or vertebrate ever recorded occurred around 2 million years ago in Europe, where more than 100 species of carnation evolved in a short space of time. This explosion coincided with the start of a change in climate towards greater seasonality and drier summers.

Meanwhile, Madagascar's legendary biodiversity seems to owe a debt to shifting ocean currents, which brought the island's animal ancestors from mainland Africa around 50 million years ago

Similarly, a key event influencing biodiversity in the Americas was the formation of the Panama land bridge joining north to south between 3 and 4 million years ago. The big crunch allowed mammals to migrate into new habitats and diversify. Recent research indicates that the formation of the land bridge was also responsible for the migration and speciation of various tropical birds.

Plate tectonics also appears to play a role in marine biodiversity. The main biodiversity hotspot in the Malay Archipelago is right in the region where the Eurasian, Australian and Pacific/Philippine Sea plates collide, creating lots of new and varied habitats.

Indeed, high levels of marine biodiversity often seem to coincide with vigorous plate tectonics. Fossil evidence shows that over the past 50 million years at least three such biodiversity hotspots have arisen in the same location as major tectonic events.

seem to hold consistently. "There are more exceptions to this rule than strong examples," says Jablonski, "which means it's not much of a rule."

So what are the alternatives? Some researchers have argued that speciation rates, both terrestrial and marine, could be much higher in the tropics, making them a "cradle" of biodiversity. Others have suggested that extinction rates are the decisive factor, with species less likely to become extinct near the equator than at higher latitudes, making the tropics a "museum" of biodiversity.

To tease out these alternatives, Jablonski and his colleagues focused on three key factors: the rate at which species have evolved in any given location, the local extinction rate, and the immigration rate of new species. In a painstaking study, they found that three-quarters of marine bivalve genera that exist today evolved in the tropics and then spread out towards the poles, while also remaining in their original habitat. So the tropics are a cradle of biodiversity. But that's not all. There are also a number of old genera in the tropics, indicating that extinction rates are lower in the tropics than in temperate regions. So the tropics are also a museum of diversity. The team concluded that their findings support an "out of the tropics" theory to explain decreasing diversity towards the poles. Since then, a few other teams have found more evidence that the tropics are both a cradle and a museum of biodiversity.

Not all research backs the idea, though. In 2009 Martin Buzas of the Smithsonian Institution in Washington DC and Stephen Culver of East Carolina University in Greenville, North Carolina, published a study of all 259 species of foraminifera – single-celled, seabed-dwelling animals – living along the Atlantic coast of North America. They found not only that equal numbers of these originated in tropical and temperate regions, but that three-quarters of the species that had evolved at higher latitudes were now also found in the tropics. These results are very interesting, says Jablonski, although he points out that the Caribbean underwent a major extinction event between 2 and 3 million years ago, which might at least partly account for Buzas's findings.

Some like it hot

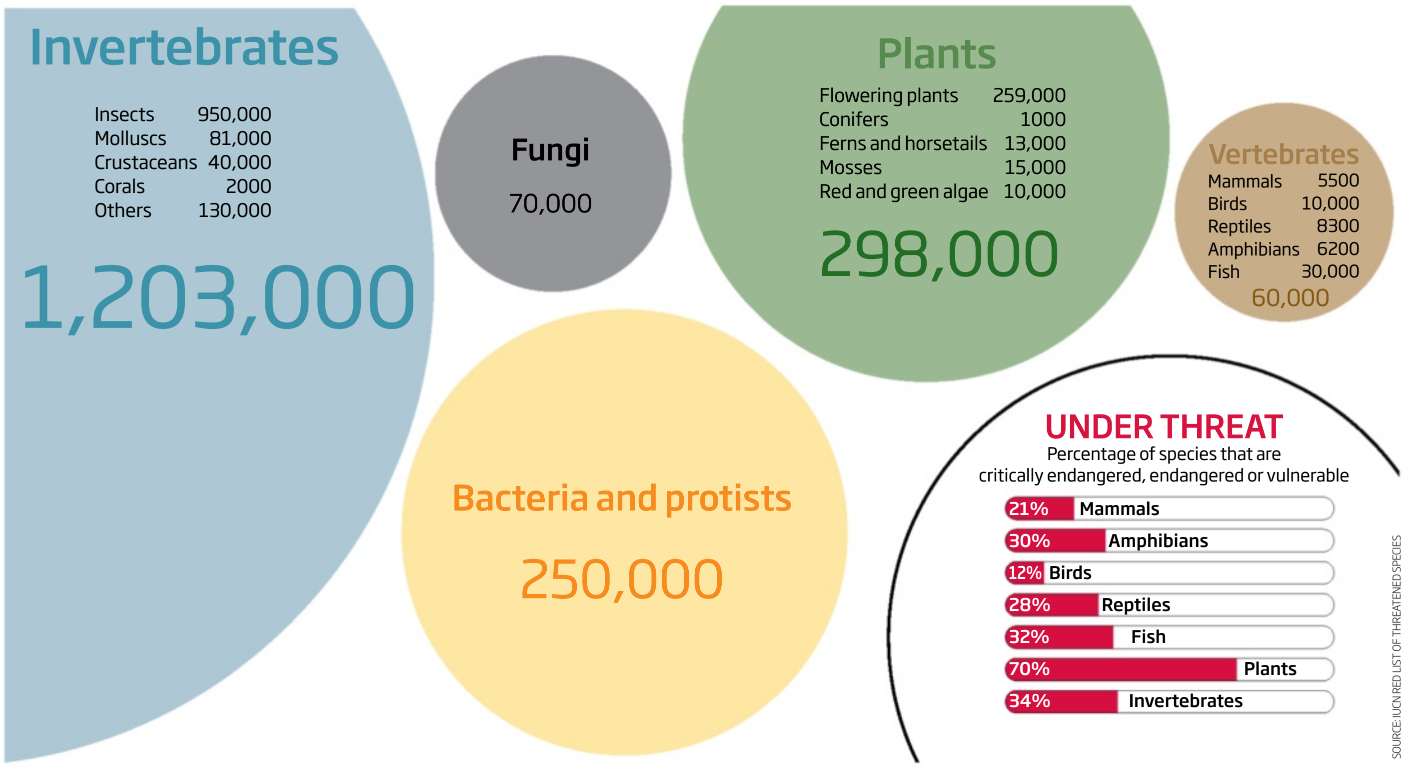
If the tropics are indeed the "engine" of biodiversity, with more species evolving here than anywhere else, why could this be? Shane Wright at the University of Auckland, New Zealand, has a possible explanation. He compared the genes of 45 common tropical plants with plants from cooler regions, and found that the tropical species had more than twice the rate of molecular evolution. Warmer temperatures could increase metabolic rates and rates of DNA replication, Wright suggests. This would raise

Lack of both sunshine and surface area may limit polar diversity

SUZI ESZTERHAS/MINDEN PICTURES/FLPA

Life as we know it

Our best estimates so far put the number of species between 1.4 and 1.9 million



the mutation rate, which, via natural selection, could lead to a proliferation of new species.

The idea has its detractors, however. "I don't think DNA replication rates are driving speciation," says Stuart Pimm at Duke University in Durham, North Carolina. "If it were just temperature, then deserts would have more species." He also points out that marine diversity varies considerably within equatorial regions.

Nevertheless, warmer temperatures may at least be important for sustaining biodiversity by providing plenty of energy to fuel crowded ecosystems. This seems to be the case in Yasuni National Park. It is consistently warm, with average monthly temperatures between 24 °C and 27 °C, and temperatures by night never dropping below 10 °C, which can damage tender plants. The steady climate means fruit and flowers are always available, providing plenty of food for animals. As well as sunshine, Yasuni also has plenty of that other stuff of life – water – with higher rainfall than the Amazonian average. "As best as we can tell, one of the driving forces for Yasuni's extraordinary biodiversity is that it is ever warm and ever wet," says Finer, now at the Center for International Environmental Law in Washington DC.

Jablonski agrees that such conditions may help explain high tropical biodiversity. "Energy input – perhaps not its mean annual value but some combination of annual average and seasonality – is very likely to be an important factor," he says. In the oceans also, Jablonski's team has found a strong relationship between the amount of energy from the sun entering a region of water and the number of species present. In addition, stable levels of sunlight can mean stable levels of nutrients in the ocean, though more work is needed to understand the impact of this on marine diversity, he adds.

"Conserving the tropics is essential. Disrupt them and you cut off the source of diversity at all latitudes"

Finding that biodiversity is correlated with temperature and nutrient availability is just the start. The mechanisms by which factors such as these might generate the global biodiversity gradient are still open to debate. Unravelling this puzzle is a huge challenge that will require the analysis of massive environmental and diversity data sets. Improvements in computing power are making this increasingly possible, says Jablonski. But he cautions that there may not be one simple solution to explain global biodiversity. "It might be that we'll look back and think that our biggest step forward was the realisation that different groups of organisms built their latitudinal gradients by different mechanisms and over different timescales," he says.

Meanwhile, the knowledge we already have can be put to good use to guide our conservation efforts. "The tropics aren't just the biggest reservoir of biodiversity, they are also the engine of biodiversity – the crucible where major adaptations and new lineages are formed," says Jablonski. "So the conservation of the tropics is essential. Disrupt that engine beyond recovery, and you have not only stalled tropical diversification, you've cut off the source of diversity at all latitudes. It's a global issue." ■

After the fall

Humans are causing a mass extinction, but we will also shape life's recovery, says **Michael Le Page**

A 3-metre-tall kangaroo; the car-sized armadillos called glyptodons; giant lemurs and elephant birds from Madagascar. Almost as soon as humans evolved, we began killing off other species, not just by hunting but also by changing the landscape with fire.

Now we are altering the planet more rapidly and profoundly than ever, and much of the diversity produced by half a billion years of evolution could be lost in the next few centuries. We are triggering a mass extinction that could be as severe as the one that ended the reign of the dinosaurs.

Given enough time, biodiversity will recover. Extinctions create new evolutionary opportunities for the survivors: the blossoming of mammals after the dinosaurs died out ultimately led to our evolution, after all. But the aftermath of this Anthropocene extinction will not be like any other. Humans have become the main driving force in evolution – and life will never be the same again.

The list of threats we pose to biodiversity is long. We are killing many creatures directly, destroying habitats, introducing exotic predators and diseases and pumping out pollution. Already, around a tenth of birds, a fifth of mammals and a third of amphibians are regarded as threatened.

Rapid climate change will make matters even worse. Warming threatens a lot of species that might otherwise be able to cope with the changes inflicted by humans, says Chris Thomas at the University of York in the UK. To work out how many species are at risk, Thomas and colleagues looked at the climatic conditions required by 1000 representative species and used them to work out how much habitable area would remain for each if the world warmed by between 1.5 and 2.5 °C. Based on these figures, the team estimated that between 15 and 37 per cent of species will be "committed to extinction" by 2050.

"There are very large uncertainties," Thomas admits. "But it is equally likely for things to be worse than we are suggesting." Indeed, without drastic action the world will warm by far more than 2 °C. "We are subjecting our biota to environmental conditions not seen for more than 10 million years," Thomas says.

The combination of so many different challenges will make it increasingly difficult for species to cope. "It's this perfect storm of extinction drivers that's the problem," says David Jablonski of the University of Chicago.

Loss of diversity is not just the result of these challenges, it is also part of the problem. Plummeting population levels have already ›

To have any chance of conserving biodiversity, we need to direct our efforts wisely. A global map constructed by researchers at the Durrell Wildlife Conservation Trust in Jersey, UK, should help. Focusing on vertebrates, it identifies the 100 ecological regions where species richness, endemism and the threat of extinction are highest

Rapid climate change may leave polar bears high and dry

COLIN HUTTON/MILLENNIUM IMAGES   SOURCE: *PLoS ONE*, VOL 5, P E8923

greatly reduced the genetic diversity within many species, decreasing their chances of adapting to changing environments by depriving them of the raw material needed for evolution. As well as this, extinctions can lead to further extinctions, because so many species depend on others. And as ecosystems become less diverse, they generally become less resilient to change. "The worse it gets, the worse it gets," says Jablonski.

The collapse of ecosystems will have huge economic consequences. From flooding in Haiti to dust storms in Beijing, the effects of environmental degradation are already hitting us hard. The loss of more coral reefs, for instance, would be a disaster for many fisheries and tourist resorts, and their death and erosion will leave formerly protected coastlines vulnerable to the ocean.

Dawn of the minifauna

Some believe there is still time to stave off the worst. "The level of extinction can be considerably modified," says David Western of the African Conservation Centre in Nairobi, Kenya. For example, we must restore animals' freedom to move, as trying to protect areas of high biodiversity will not work if species are trapped in increasingly unsuitable climate zones. Transporting species to areas that have a more suitable climate is also an option, although an expensive one.

Other researchers are more pessimistic. "We can turn the ship a little," says Jablonski. The main problem he sees is a lack of political will.

No one can predict exactly what the Earth of our descendants will look like. However, there are some clues in what's happening right now. Our influence is so profound that we are altering the evolutionary pressures that shape life. There have already been very large and quick behavioural changes as landscapes become "humanscapes", says Western. Foxes and coyotes are adapting to life in cities, and elephants have started moving out of parks at night to feed at the fringes of settlements before returning in the morning to avoid us. Human pressures are also producing genetic changes in wildlife. As a result of poaching for ivory, for instance, tuskless elephants are evolving. "There will be a new round of evolution," says Western. "We are already seeing that."

Almost all biologists believe that the age of megafauna is over. Large, slow-to-reproduce animals are the most likely to become extinct and, at least on land, those that do survive will not have the vast expanses of habitat needed for further speciation. The greater pressures on large animals will downsize entire communities, says Western. For example, small antelope are likely to become more common than larger herbivores on the African savannah, which would lead to lions becoming smaller too. Lions may also become more benign as we kill off the aggressive individuals that encroach on human settlements. "There will be a transformation of large animals to ones that are compatible with the humanscape," Western says.

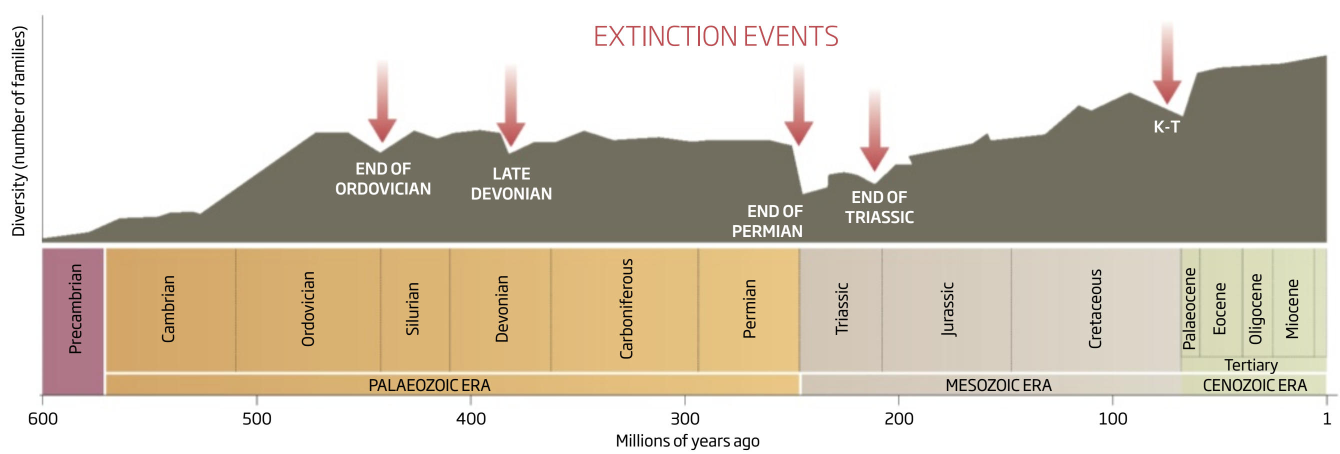
The species most likely to thrive will be small ones that are easily spread around by humans and good at colonising new territory – pests, weeds and pathogens. "It's not good to be big or rare," says Jablonski. "You want to be a rat, or a weed, or a cockroach." In theory, as humans fragment habitats, evolution may throw up new species, especially small mammals and insects – but these might not be very resilient. They may limp along and easily go extinct, Jablonski says.


STUART FRANKLIN/MAGNUM

So the ecosystems of the future are likely to be far poorer affairs, with fewer species, fewer links between species and a dearth of large animals. Anyone who has dived on a degraded

Explosions and extinctions

Life's ups and downs through the ages



Pollution from a nickel smelter ravaged this Russian forest

reef knows the sort of thing to expect: a dazzling array of corals swarming with fish of all shapes and sizes giving way to algae-covered rocks with barely a tiddler in sight.

After previous mass extinctions, the recovery of biodiversity took millions of years. Coral reefs, for example, did not reappear until about 10 million years after the Permian-Triassic extinction (see diagram, left). The recovery from the Anthropocene extinction could be different, however, as we are already laying the foundations that will allow our descendants to speed up the process.

For starters, we are preserving samples of endangered species so that they can be revived if necessary. There are some 1750 plant "gene banks" worldwide storing samples from an estimated 7.4 million species, mostly food plants but also some wild species. Animals are also being stored as frozen tissue samples. The Frozen Zoo at San Diego Zoo in California contains over 9000 cell cultures from nearly 1000 species, and many similar projects exist around the world.

Even assuming that civilisation survives and that gene banks get the funding they need to store many more samples, to look after them for the next few centuries and to revive species as suitable habitat becomes available, only a tiny fraction of the world's species could be saved this way. Nevertheless, that fraction could include not only many charismatic megafauna – revived by cloning, perhaps – but also keystone species that play a vital role in maintaining ecosystems, such as corals. The Global Coral Repository, a collaboration between the Zoological Society of London, the University of Oxford and the non-profit Haereticus Environmental Laboratory, recently started a project to "cryobank" every species of coral on the planet. The frozen samples can be revived simply by thawing.

"The recovery from the Anthropocene extinction could be far faster than previous mass extinctions"

The second thing people could do to aid the recovery of biodiversity would be to manage habitats in a way that allows evolution to continue. This is now being tried in the Cape region of South Africa, home to some of the most diverse flora in the world. "Species come and species go," says Richard Cowling of the Nelson Mandela Metropolitan University, Port Elizabeth. "You've got to preserve the processes."

To that end, Cowling has helped to devise a conservation plan for the region that focuses on preserving not only distinct kinds of habitats, but also the gradients between them, such as between soil types and microclimates. The idea is that environmental gradients produce genetic gradients within species as subpopulations adapt to local conditions. The resulting diversity can give rise to new species if, say, the populations at the extreme ends of the gradient become isolated.

In the future, ecologists might go even further and actively manage ecosystems in a way that promotes evolutionary processes that produce biodiversity. "It's a damn good idea," says Cowling.

Finally, we might generate diversity in an even more direct way. We have already created millions of new varieties of plants and animals through selective breeding, and many of these creatures, from mustangs and burros to the dingo, have established feral populations. In the vacuum left by a mass extinction, many more domesticated species may turn wild – and genetically modified domesticates could have a particularly dramatic impact.

Take the increasing interest in boosting the efficiency of photosynthesis to increase food production. Most plants capture less than 2 per cent of available energy. If this proportion can be significantly increased, the resulting "superphotosynthesisers" might outcompete many wild plants over the next few millennia, compounding biodiversity loss. On a geological timescale, however, they could lead to unprecedented levels of diversity, because more energy would be available to life than ever before.

Things might get wilder still if we create artificial life. Some researchers are trying to produce truly synthetic organisms whose chemistry is unlike anything alive today. It is unlikely that such organisms could survive outside laboratories, as they would have to compete with species honed by billions of years of evolution, but it might just happen.

This vision of a world in which biodiversity depends largely on clones of long-extinct creatures, feral animals, genetically modified organisms, human-directed evolution and perhaps even artificial life will sound like a nightmare to many people. But it is just a continuation of the process that began as soon as our ancestors started reshaping the landscape and meddling with evolution. And if we don't do more about the accelerating rate of extinctions, it is perhaps the best outcome our descendants can hope for. ■

CHAPTER SIX

TIME

NATALIE NICKLIN

It flies, it drags and sometimes it seems to stand still. We keep it, waste it and wish we had more of it. Time feels so natural to us that it is easy to forget just how stunningly peculiar it is.

The more we learn about time, the more unsettling it becomes. Why does it only flow in one direction? Is it real, or a figment of the imagination? How did it start? Will it ever end? Is time travel possible? And can time point us to that frustratingly elusive theory of everything?

Prepare to dig deep into the past, present and future of the most mysterious dimension of all.

The origin of time

Join us on a journey through time at every scale - from the briefest flash to the age of the universe

scale in seconds

10^{-18}

10^{-17}

10^{-16}

Fastest laser pulse

67

attoseconds

10^{-15}

10^{-14}

WHAT is time? It is a question that has occupied some of the greatest minds, from the ancient philosophers to the scientists of the Enlightenment and beyond.

Yet after thousands of years of contemplation and scientific progress, there remains no consensus about its nature. "We can recognise time but we do not understand it," says independent philosopher Julian Barbour. "It is remarkable that there's so little agreement on what time is or even how to investigate a solution."

This may be because a deep understanding of time has proved almost superfluous to our progress. In physics, for example, Newton's laws of motion, Einstein's general relativity and quantum theory do not require us to know the nature of time in order to make them work. Even clockmakers do not need to understand time.

Clocks, however, do give us a clue about where to concentrate our efforts because a clock needs some kind of moving part to gauge the passing of time. This can be the tick-tock of an escapement, an oscillating quartz crystal or the ejection of a particle from a radioactive atom – one way or another, there must be movement.

When something moves, it changes. So clocks tell us that time is inextricably linked somehow to change. Yet that only takes us so far. From this point, there are two paths that lead to completely opposing views of time.

The first concludes that time is a real, fundamental property of the universe. Like space or mass, it exists in itself. It provides the framework in which events take place. This was the view taken by Isaac Newton, who realised that to quantify motion, you have to treat time as if it is as solid as the walls of a house. Only then can you confidently measure how far and how fast an object is moving.

Einstein got rid of this notion of rigidity by showing that time passes at different rates depending upon an observer's motion and the strength of gravity pulling on the observer. His theory abandons the notion that space and time exist in themselves and he even went so far as to say "time is nothing but a stubbornly persistent illusion". Yet space-time can still provide a useful reference frame against which to measure the cosmos, or as physicist Brian Greene of Columbia University in New York wrote in his 2005 book *The Fabric of the Cosmos*: "space-time is a something".

The second path leads to the idea that change is the fundamental property of the universe and that time emerges from our mental efforts to organise the changing world we see around us. Newton's great rival Gottfried Leibniz favoured this style of interpretation, which suggests that time is not real but created inside our brains. So we are faced with a conundrum: is time real?

Physicists and philosophers are still very much debating the issue, not least because quantum mechanics muddies the issue further. One of the main reasons, though, is that the answers could lead us towards a "theory of everything" that would explain all the particles and forces of nature (see "Countdown to the theory of everything", page 81).

Another question looms large too. If time is real, where did it come from? Until recently, most physicists assumed that it was created in the big bang when matter, energy and space

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itself were born. Any notion that time existed before the big bang was therefore considered irrelevant.

Now, however, they are not so sure. "We have no right to claim that the universe and time started at the big bang, or had some sort of prehistory," says Sean Carroll at the California Institute of Technology in Pasadena. "Both options are very much on the table, and personally I favour the idea that the universe has lasted forever."

String theories are what have led to this re-evaluation. In these hypothetical extensions to standard physics, reality is composed of more dimensions than

our familiar four. Although we cannot directly perceive these other realms, they provide places for alternate universes to exist. These universes bud off from each other in a perpetual sequence of big bangs, meaning that our universe was born from another and so time did exist before our big bang. Previous universes may even have left hints of themselves on ours.

In 2008, Carroll and colleagues hinted that peculiarities in the radiation leftover from the big bang may be the signature of earlier universes. In 2010 Roger Penrose at the University of Oxford and Vahe Gurzadyan at Yerevan Physics Institute in Armenia went much further and argued that circular patterns in this cosmic microwave background were evidence of a sequence of previous universes and big bangs. There was hope that a detailed map of the CMB, released in March 2013, would provide more evidence but as yet there is nothing solid.

For the moment there is simply no way of escaping the fiendish difficulty of these questions, nor can we conceive of the profundity their answers will one day bring. Now, more than ever, we have to face up to our ignorance of time. **Stuart Clark** ■

Time's arrow

"We have no right to claim that time or the universe started at the big bang"

TAKE a few steps forward, turn around and walk back. No problem. Now let a few seconds pass, then turn around and head back a few seconds in time. No luck? Of course not. As we know only too well, time, unlike space, has only one direction – it flows from past to future, and never the other way round.

That all sounds like the natural order of things, but if you look closely enough at nature, you will find that it isn't. A thorough search of the laws of physics turns up no such arrow of time. For example, you can use Newton's laws of motion to work out where a ball was thrown from in the past just as well as where it will land in the future. And when it comes to particles, the laws and forces that govern their behaviour do not change if you swap the future for the past.

"The truly odd thing is that the laws of physics, which surely ought to be responsible for what we see in the world, can work just as well both forwards and backwards in time," says Dean Rickles, a philosopher of science at the University of Sydney in New South Wales, Australia. "There shouldn't be an arrow."

If time's arrow is not in the laws of physics, where does it come from? An important clue emerges from the complex interactions of large numbers of particles. Every object you see around you, including you, is made up of a vast collection of particles. These particles are not just sitting around – they are constantly shuffling about and rearranging.

To any macroscopic system – say, a puddle of water or a crystal of ice – physicists assign an entropy. Entropy reflects the number of ways you can rearrange a system's constituent particles without changing its overall appearance. A puddle of water can be made by arranging H_2O molecules in a huge number of ways, making it a high-entropy system. An ice crystal, on the other hand, has to be arranged in a very precise way, and because there are fewer ways to do that it has a low entropy.

In terms of pure statistics, high-entropy systems are always more likely than low ›

ones since there are so many more ways to produce them. That's why, given temperatures warm enough to allow molecules to move around into new arrangements, you'll always see ice turn to water, and never see a puddle spontaneously crystallise into ice. Indeed, if you were watching a film and saw a scene where a puddle suddenly froze on a warm day, you would assume the film was playing in reverse – that time was moving backwards.

Even though entropy increase is a statistical, and not fundamental, phenomenon, it is enough to give rise to a powerful pillar of physics: the second law of thermodynamics. According to the second law, the entropy of the universe can never decrease. And there, you might think, lies the key to time's arrow – the steady march from low entropy to high is what we perceive as the passage from the past to the future.

If only it were so easy. Unfortunately the second law does not really explain the arrow of time. It merely says that high-entropy states are more likely than low entropy ones. Time does not enter the picture, meaning that the world 5 minutes from now is likely to have higher entropy and so should the world 5 minutes ago.

The only way to explain the arrow of time, then, is to assume that the universe just happened to start out in an extremely unlikely low-entropy state. If it had not, time would have become stuck and nothing interesting, like us, would ever have happened. "Time's arrow depends on the fact that the universe started up in a very peculiar state," says physicist Carlo Rovelli of the Centre for Theoretical Physics in Marseille, France. "Had it started up in a random state, there would be nothing to distinguish the future from the past."

In fact, observation proves that the universe did start out in a low-entropy state. Radiation left over from the big bang provides a snapshot of the infant universe. It shows that near the beginning of time, matter and radiation were spread extremely smoothly throughout space. On first glance, that looks like a high-entropy state – until you take gravity into account.

Gravity always wants to clump things together, so in a system governed by gravity, a black hole is a far more likely state, and so is of higher entropy than a smooth distribution. This low-entropy smoothness is extraordinarily unlikely – so how did we get so lucky? "If we can explain the low-entropy past, then we will have pretty much cracked the problem of time's arrow," says Rickles.

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Cosmologists do have an explanation for the smoothness we see in the early universe. In the first fraction of a second after the beginning of time, the universe went through a brief but dramatic burst of expansion known as inflation, which stretched space like a rubber sheet and smoothed out any wrinkles.

Inflation seems to solve the dilemma. On closer inspection, however, it only pushes the problem back. In order for inflation to occur in the right way to produce our universe, the field driving the expansion, known as the inflaton field, has to have some remarkably unlikely properties. So while the inflaton field explains the mystery of the low-entropy universe, it itself has low entropy. How do physicists account for that?

One possibility is that inflation didn't happen just once. Let's say the inflaton field started out in a chaotic, high-entropy state – a more likely scenario – so that its properties varied from place to place. The low-entropy inflaton that gave rise to our smooth universe and therefore our arrow of time would be just a random blip in a larger, high-entropy field. Some parts of the field would have the right conditions to produce a universe like ours; others would remain sterile or would produce other universes.

"Why is it that human brains remember only the past?"

In fact, the physics of the inflaton field guarantees that there's always enough left over to create more universes – inevitably leading to an infinite multiverse.

Several strands of evidence now converge on the multiverse, leading many cosmologists to take the idea seriously. In a multiverse, some universes would have arrows of time while many more would not. We should not be surprised to find ourselves in one that does, since that is the only kind of universe that could give rise to life. "This is my favourite scenario," says physicist Sean Carroll of the California Institute of Technology in Pasadena. "It hasn't

completely caught on yet, but I hope that before too long everyone will think it's completely obvious."

But even if the multiverse can account for the arrow of time, many mysteries remain. For instance, how does the second law fit in with the quantum nature of the universe? Quantum systems seem to display their own kind of arrow: they are always described by superpositions of possible states until a measurement mysteriously selects one unique state, a process that appears to be irreversible. Neuroscience provides its own mysteries too. Why do human brains only remember the past and not the future?

"Understanding how the arrow of time actually manifests itself in numerous circumstances – evolution, ageing, memory, causality, complexity – is still a wide vista of unanswered questions," says Carroll.

Hopefully physicists will have more answers in the future – assuming, of course, that there is such a thing. **Amanda Gefter** ■

10^{-13}

10^{-12}

10^{-11}

10^{-10}

Countdown to the theory of everything

RELENTLESS, elusive and infuriatingly hard to define. Not only is time one of the great existential mysteries, it also holds the key to the most ambitious challenge in theoretical physics – to express the complex workings of this vast universe in a single, elegant theory, a theory of everything.

Such a theory would unite general relativity, Einstein's theory of gravity which describes the workings of space and time, with quantum mechanics, the endlessly weird but entirely compelling and enormously successful theory that describes the physics of matter. And it is here that we have been struggling for nearly a century.

General relativity and quantum mechanics offer radically different descriptions of time, and this difference is a prime source of their stubborn refusal to be unified. If we are to make progress, something's got to give – and many suspect that it will have to be time.

Almost a century ago, Einstein showed that time is not the fundamental ingredient of reality we once thought it was. His theory of general relativity sewed space and time into a unified entity called space-time, which can stretch and wrinkle in the presence of matter or energy, producing the space-time curvature we feel as the force of gravity.

But the problem with space-time is that it is frozen. Space-time as a whole cannot develop over time because it *is* time – no clock can sit outside the universe.

According to general relativity, what we experience as the flow of time is a kind of illusion generated by the patchwork ways in which different observers slice the unified space-time into space and time with their individual points of view.

In quantum mechanics, the situation is drastically different. Unlike general relativity, where time is contained within the system, quantum mechanics requires a clock that sits outside the system, ticking away the seconds of the universe in exactly the same way for all observers. That's because quantum systems are described by wave functions, which encode the probabilities of the outcomes of any measurements one might choose to make, and those wave functions develop over time.

It is a fundamental rule of quantum mechanics that the probabilities remain the same as time passes. To enforce that rule, the time in which the wave function evolves must be one and the ›

Desktop computer calculation

120

picoseconds

same for everything and everyone.

To make progress in the quest to unite general relativity with quantum mechanics, we need to work with a single view of time. But which one is the right one?

It depends on who you ask. Some believe that Einstein must be right, and quantum theory must be modified. Carlo Rovelli, a physicist at the Centre for Theoretical Physics in Marseille, France, has rewritten the rules of quantum mechanics so that they make no reference to time.

"For me, the solution to the problem is that at the fundamental level of nature there is no time at all," Rovelli says. In his view, quantum mechanics does not have to describe how physical systems evolve in time but only how they evolve relative to other systems, such as observers or measuring devices. "Physics is not about 'how does the moon move through the sky in time?' but rather 'how does the moon move in the sky with respect to the sun?'," he says. "Time is in our mind, not in the basic physical reality."

Others disagree. Physicist Fotini Markopoulou of the Perimeter Institute for Theoretical Physics in Waterloo, Ontario, Canada, has argued that time does exist at the most basic level of reality – but to accommodate time, space has got to go. In her model, dubbed "quantum graphity", reality's basic ingredients are quantum events that are ordered in time, and from them space, along with gravity and Einstein's theory, are expected to emerge at larger scales and lower energies. In this scenario, quantum theory wins the time battle, and general relativity just has to make do.

For still others, it is not enough to declare quantum mechanics or general relativity the time victor. According to Dean Rickles, a philosopher of science at the University of Sydney in New South Wales, Australia, neither theory is ultimately right. "It is highly likely that what we think of as time emerges from some deeper, more primitive non-temporal structure," he says.

As for the theory of everything, says Rickles, "there is a long way to go, but it certainly seems that the concept of time will play a crucial role". **Amanda Gefter** ■

Light travels one metre

3 *nano-seconds*

10^{-9}

10^{-8}

10^{-7}

10^{-6}

10^{-5}

The rhythms of life

IN 2013, a school in London made an announcement that must have been music to the ears of its older pupils: their classes would now start at the slightly later time of 10 am. The UCL Academy wasn't encouraging students to slack. It was responding to research showing that teenagers perform better if they start later.

The school doesn't yet know whether the experiment has borne fruit. But if the experience of Monkseaton High School in Tyneside, UK, is anything to go by, it will. When it introduced a later start time in 2009, absenteeism fell, punctuality improved and exam results went through the roof.

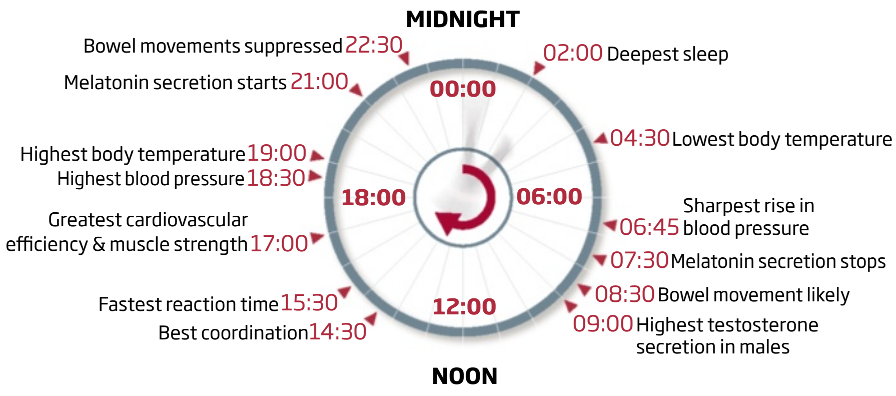
The changes are designed to synchronise the school day with pupils' body clocks. Teenagers are notoriously owlish, preferring to stay up late and sleep in till lunchtime. This isn't entirely by their own volition: natural delays in secretion of the sleep hormone melatonin causes their body clocks to be shifted backwards. By aligning the school day with these biological rhythms, The UCL Academy hopes to avoid teaching teenagers when their brains are still half asleep.

In the modern world our lives are largely dictated by time. But even in the absence of clocks, schedules and calendars, our bodies still march to the beat of internal timekeepers called circadian rhythms. Over each 24-hour period we experience cycles of physical and mental changes that are thought to prepare our brains and bodies for the tasks we're likely to encounter at certain times of day.

The most obvious is the sleep-wake cycle, but there are many others. Circadian rhythms affect everything from how we perform on physical and mental tasks to when drugs are more likely to work. "We're

THIERRY ARDOUIN/TENDANCE FLOUE

A guide to circadian rhythms



SOURCE: PHYSIOMICS

not the same organism at midday and midnight," says Russell Foster, whose work on body clocks at the University of Oxford was influential in UCL's decision. More schools should follow suit, he says.

The main driver of circadian rhythms is a tiny patch of brain tissue called the suprachiasmatic nucleus (SCN), located just above the optic nerves. This master clock gathers information about light from the retina and relays it to the rest of the body via nerve impulses and hormones.

Among these are the sleep hormone melatonin and its opposite number orexin. The SCN also imposes its rhythms on immune function, digestion, cell division, body temperature and more. Its own pattern of activity is reset each day by light, and this influences the expression of a handful of "clock genes" whose activity follows a 24-hour cycle.

The SCN isn't the be-all and end-all of biological timekeeping. Many of the body's cells also contain clocks of their own which have peaks and troughs of activity throughout the day. For example, inflammation-causing immune cells called mast cells are more active in the early morning, which may be why immune disorders such as asthma are more troublesome at this time. Skin cells also show circadian rhythms, proliferating at night and producing more oil during the day, while cells in the stomach that release the hunger hormone ghrelin also seem to be controlled by a circadian clock.

These local clocks are not completely independent of the master clock. The SCN is thought to act like the conductor of an orchestra, producing a regular signal from which the rest of the musicians take their cues. "If you shoot the conductor, the members of the orchestra will keep on playing, but they're all playing at slightly different times so the rhythmicity falls apart," says Foster. People whose SCN stops functioning because of injury or ›

"Even in the absence of clocks, schedules and calendars, our bodies march to the beat of internal timekeepers"

disease lose their regular 24-hour cycle.

Not surprisingly, our physical and mental states vary widely with the time. Core body temperature is at its lowest at around 4.30 am and peaks at around 7 pm. Adrenalin levels also rise throughout the day.

These changes can affect how we perform. "There is fairly comprehensive evidence of circadian rhythms in many aspects of human performance, including athletic," says Jim Waterhouse of Liverpool John Moores University, UK. As your body temperature and adrenalin levels rise during the afternoon, physical performance tends to improve. Meanwhile the ability to carry out complicated mental tasks like decision-making is negatively affected the longer you have been awake.

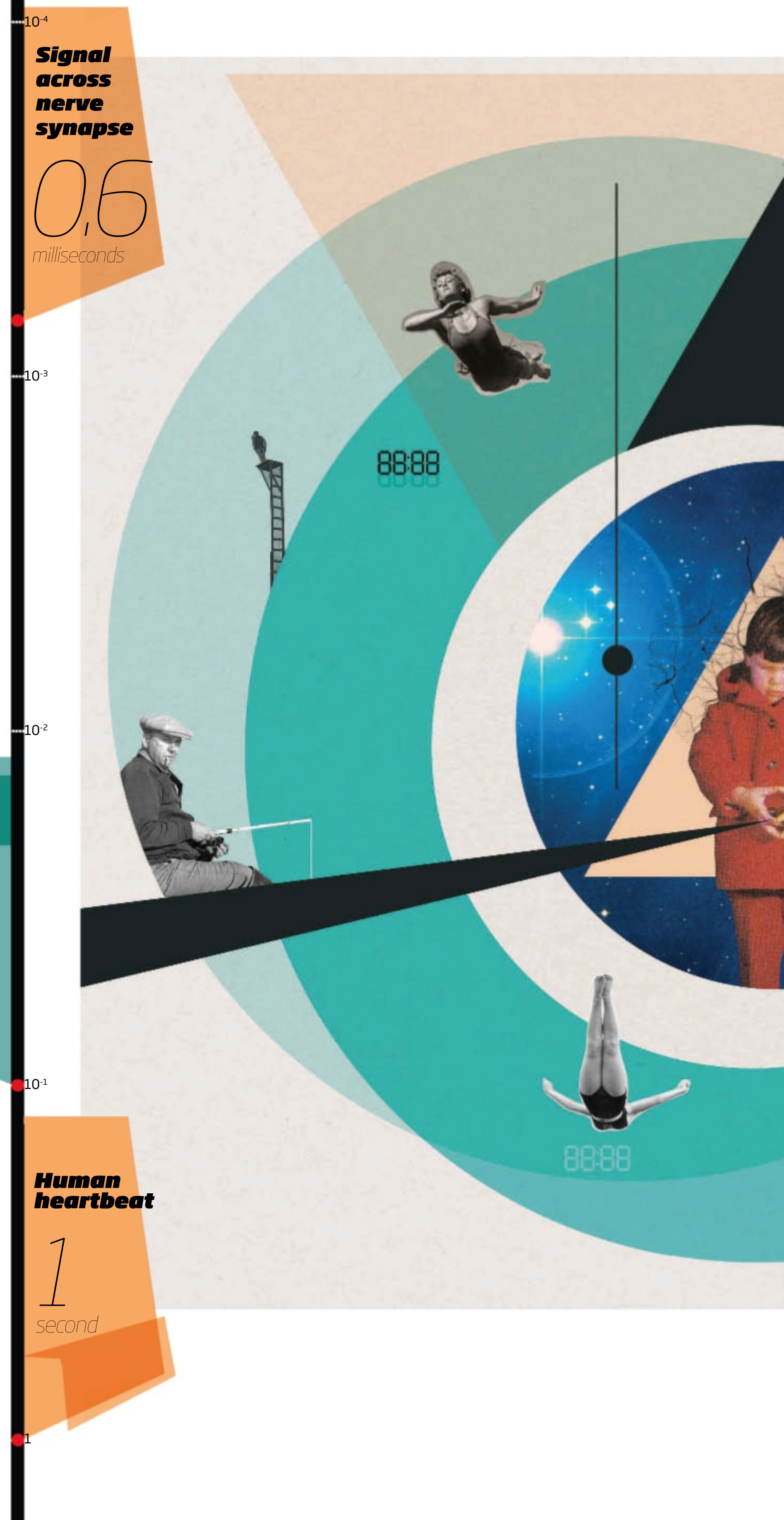
Not everyone follows the same pattern. Some people are larks, preferring to rise early and retire early, while owls find it difficult to function in the morning but thrive late at night. These "chronotypes" are largely determined by genes. Most of us fall somewhere in the middle.

At the extreme end of the spectrum are people with a rare disorder called familial advanced sleep-phase syndrome (FASPS), who wake naturally in the early hours of the morning and fall asleep in the early evening. FASPS is caused by a single mutation in a gene called *PER2*, one of a handful of clock genes responsible for setting the SCN.

Clocks can also be nudged forwards by exposure to bright light in the early morning, though preliminary evidence suggests that some people's clocks are more resistant to resetting than others, says Steven Brown of the University of Zurich in Switzerland. This might explain why some people are more susceptible to jet lag and find it harder to adapt to shift work than other people.

Age can also cause profound shifts. Older people tend to sleep less and wake earlier. Brown's lab recently discovered a factor in the blood of elderly people that can shift the circadian rhythms of skin cells towards the lark end of the spectrum.

This discovery suggests it might be possible to develop drugs that turn owls into larks and vice versa. "That could be useful not only for older individuals, but for shift workers and people with sleep syndromes," says Brown. Though don't hold out any hope of sleepy teens ever being bright-eyed and bushy-tailed at 9 am. **Linda Geddes** ■



NATALIE NICKLIN

The clock in your head

TRY to count off 5 seconds in your head. Chances are you managed it pretty accurately. But have you ever stopped and wondered how your brain achieves this amazing feat?

Time perception is one of the enduring mysteries of the brain. While we have a fairly good grasp on the millisecond timing involved in fine motor tasks and the circadian rhythms of the 24-hour cycle (see "The rhythms of life", page 82), how we consciously perceive the passage of seconds and minutes – so-called interval timing – remains decidedly murky.

For a start, there is no dedicated sensory organ for time, as there are for touch, taste and smell. Time is also unusual in that there is no clinical condition that can be defined purely as a lack of time perception, which makes it hard to study. "What we really want is someone who is as bad at timing as amnesiacs are at memory," says John Wearden of Keele University in the UK. "But there are no such people."

Some believe there's a reason for this. Warren Meck of Duke University in Durham, North Carolina, thinks timing is so fundamental to cognition that our brains have developed several back-up systems that can kick in if the main clock is damaged, which is why it is so difficult to find anyone who cannot perceive time.

As for what the biological basis of such clocks might be, nobody really knows. Various models have been put forward. Some suggest the brain has a dedicated timekeeper, others that time is measured as a by-product of general mental processes such as the gradual fading of memories.

For the past 50 years the most influential of these has been the "pacemaker-accumulator model", which proposes that the brain has a dedicated clock emitting regular pulses which are stored in an accumulator, where they can be counted to estimate how much time has elapsed.

The problem with this model is that while it fits with observations of time perception, it is short on specifics. It doesn't say what the pacemaker is, where it is located, what the pulses are, where they are stored or how they are counted. Various new ideas have been put forward recently but the problem remains unsolved.

A complete theory of time perception will also have to explain why it is so flexible. Cocaine, amphetamine and nicotine have all been shown to speed up time perception, while some antipsychotic drugs slow it down. All interfere with the neurotransmitter dopamine. People with disorders in the dopamine system, such as those with Parkinson's disease or schizophrenia, also suffer distortions in their perception of time.

Time can be stretched and shrunk in other ways. It seems to slow down when you are frightened and flies when you are having fun. Time seems to pass more quickly as you get older.

The key to these puzzles may be how we think about how we perceive time. "We're under the illusion that time is one thing, but we can take various ›

"Time seems to slow down when you're frightened and flies when you're having fun. And it seems to pass more quickly as you get older"

aspects of time and manipulate them separately from the others," says David Eagleman of Baylor College of Medicine in Houston, Texas. That might mean our perception of it also has several components.

Perhaps the best illustration of the different ways we can perceive time is an experiment in which Eagleman persuaded study participants to be dropped backwards off a tall tower into a safety net 30 metres below. As they fell, they were asked to look at a wrist-worn LED display showing a number that alternated with its negative image 20 times a second. Usually this is too fast to be perceived, but if "brain time" really does slow down in scary situations they should have been able to read the number.

Although the participants reported that the fall seemed to last about 35 per cent longer than the 2.5 seconds it actually took, none of them could read the number.

The reason time seems to slow down when you are falling, Eagleman suggests, is that intense or novel situations command our attention and cause our brains to soak up more detail. Eagleman has shown that when the brain is exposed to the same image over and over, and is then confronted with a different image, the new one seems to last longer, even though it is displayed for the same period of time. The brain also uses more energy when exposed to the new image. "The length of time something seems to have lasted appears to correlate with the amount of energy the brain uses to record an event," Eagleman says.

This observation may also help explain why time speeds up as we get older. For children everything is new and the brain is processing vast amounts of information about the world. As we age and the brain learns the ropes, it ceases to record as much information. "It is as if at the end of a summer you look back and you don't have that much footage, so it seems to have gone by more quickly," says Eagleman.

This might suggest that we can stretch our subjective lifetimes by packing in as many different and exhilarating experiences as possible. The trouble is finding the time. **Linda Geddes** ■

Personal time warps

Einstein showed how elastic time can be. His special and general theories of relativity describe the slower ticking of moving clocks and the time-warping effects of Earth's gravity. Here's how they affect us

GETTY/ALAMY/CORBIS

SPACE AGE

Russian astronaut Sergei Krikalev has spent longer in space than anyone else – 803 days, 9 hours and 39 minutes in total. While space's weaker gravity aged him, this was outweighed by the rejuvenating effect of his high speed. So he is 21 milliseconds younger than if he had stayed put

ROUND-THE-WORLD FLIGHTS

Repeat a famous experiment carried out with atomic clocks and you will age 40 nanoseconds less if you circle the globe eastward, in the direction of Earth's rotation. Fly west, though, and you will age 273 nanoseconds extra

YOUR HEAD AGES MORE THAN YOUR FEET

...by around 10^{-11} seconds a day. Live for 80 years and that difference adds up to 300 nanoseconds

LOCATION, LOCATION, LOCATION

A year atop Australia's tallest apartment block will make you 950 nanoseconds older than a bungalow-dweller

THE YOUTHFUL DEAD SEA

Spend 40 years by the shores of the Dead Sea, at the lowest elevations on the Earth's surface, and you'll age 48 microseconds less than someone living at sea level, and 750 microseconds less than the residents of La Rinconada in Peru, at an altitude of 5100 metres

Valerie Jamieson ■

Our experience of time owes as much to cultural invention as human cognition

VERA DA SILVA SINHA

A life without time

WE ALL, regardless of our cultural background, experience time. But is everyone's concept of time the same? Anthropologists have found that ways of organising and naming time intervals vary greatly between human groups. The minutes and hours used for segmenting and measuring clock time, natural as they may seem to us, are in fact inherited from the ancient Babylonians, who first invented this notation. And different cultures have different calendars. Nevertheless, orienting ourselves in time using hours, days and months appears as fundamental to our mental and social lives as orienting ourselves in space using landmarks, routes and distances.

In fact, space and time seem to be closely related domains of human cognition, if the way we talk about them is a reliable guide. We speak of events occurring in relation to temporal landmarks, in the same way that we locate objects in relation to spatial landmarks. So an event can take place in the summer or on Friday.

We also think and speak of events, and the people that experience them, as moving on a timeline, for example "winter is approaching" or "she is coming up to her exams". Such metaphorical mapping of spatial language to that of time can be found across the languages of the world. This has led cognitive scientists to claim that using spatial concepts to talk and think about time is a universal characteristic of the human mind. But these claims are challenged by research carried out with an indigenous Amazonian community by myself (I'm a psychologist of language at the University of Lund in Sweden, though I was at the University of Portsmouth, UK, at the time), my Portsmouth colleagues Vera da Silva Sinha and Jörg Zinken, and Wany Sampaio from the Federal University of Rondônia in Brazil.

The Amondawa (pictured above), who live in a remote, forested area of the Brazilian state of Rondônia, were first contacted by the outside world in 1986. Traditionally they have lived by small-scale farming, hunting and fishing. Like many other Amazonian languages, theirs has a very restricted number vocabulary, with only four numbers, so the lack of clock time and a numerically based calendar is hardly surprising.

For the Amondawa, time during the day is marked by the sun's position in the sky, and by activities such as rising, eating and working that habitually take place at different times. With no words for month and year, longer intervals are named as subdivisions of the dry and rainy seasons. The language has no abstract term for time, and when asked to translate the Portuguese word *tempo*, speakers use the word *kuara*, or sun.

"Using spatial concepts to talk and think about time may be a universal characteristic of the human mind"

Neither do the Amondawa celebrate birthdays. People pass through named life stages, taking on a new personal name based on gender and clan with each transition. When a new baby is born, for example, it will take the name of its older sibling and that child will adopt a different name.

We tried to elicit space-time metaphors such as "the dry season is coming" from Amondawa speakers, but found that they do not use them. This is not because they do not comprehend the meaning of such expressions, since bilingual Amondawa speakers readily understand space-time metaphors in their second language, Portuguese, and the Amondawa language itself uses quasi-metaphoric expressions such as "the path goes to the riverbank". And it is not because the language grammatically precludes using spatial terms in conjunction with time-interval nouns. Amondawa speakers will happily talk about movement of the sun, *kuara*, while rejecting the same word when speaking of the temporal "motion" of the dry season.

How should we interpret these findings? Our hypothesis is that, because they have no calendar or other number-based time-measurement system, the Amondawa have no corresponding concept of "abstract" time. Their time intervals are structured around the rhythms of the natural and social world, rather than being segments of a calibrated timeline independent of and superimposed upon these worlds. Lacking an event-independent time, the Amondawa do not metaphorically "move around" in it, or "place" events in it, which accounts for the absence of space-time metaphors in the language. Amondawa time, to put it another way, is identical to the events and routines of everyday life, rather than being, as it is for us, a "technology of the mind" used for organising those events and routines.

Amondawa time strikes us as odd and remarkable. But taking a longer view of human culture, it is we who are exceptional. Small-scale societies, organised around face-to-face encounters, have been around much longer than hierarchically structured, socially differentiated ones. Traditional societies can manage without the cognitive technologies of calendar and clock. Our experience of time, it seems, owes as much to cultural invention as to the workings of the brain. **Chris Sinha**

10^1
10^2
10^3
10^4

Mayfly lifetime

2

hours

The dating game

> "The more substantial parts of human history are written largely in the language of carbon isotopes"

TIME might be mysterious, but there is one thing we can say with safety: there is an awful lot of it about. Modern cosmology dates the origin of the universe to some 13.82 billion years ago.

How do we know? Figuring out the age of the universe involves a complex series of assumptions about its geometry, expansion rate and composition, and it is only fairly recently that we have had an estimate to be happy with.

Until a few years ago, cosmological models suggested the universe was younger than its oldest stars. Now though, says Søren Meibom of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, estimates and observations have largely come together. In 2012 NASA researchers used data from the Wilkinson Microwave Anisotropy Probe, which mapped the cosmic background radiation (CMB) – considered to be the big bang's afterglow – to produce a figure of 13.75 billion years. In 2013 the European Space Agency, using data from another CMB map produced by its own Planck satellite, revised this upward to 13.82 billion.

Meanwhile, methods for estimating stars' ages have improved – although it is still a notoriously tricky business. Stellar dating involves measuring properties such as mass, chemical composition and temperature, and comparing them with models of how those properties should change over time for a particular type of star. One problem is that many of these models are calibrated by reference to the one star whose age and characteristics we can measure independently – our sun. "That can make you a little uneasy," says Meibom.

Closer to Earth, we can feel more confident in our dating skills. We think we know roughly how old our sun and its surrounds are from tracking radioactive decays in lumps of the solar system's original material that rain down from the sky: meteorites. The ratio of lead isotopes in the Allende meteorite, which fell in Mexico in 1969, gives it an age of 4.57 billion years – and, by extension, the solar system is not much older.

Such radiometric dating stands us in good stead for dating objects from Earth's beginnings almost to the present day. In a large collection of radioactive atoms, a set number will have decayed by a set time; by measuring how much of a particular atom is sealed into a rock compared with the products of its decay, we get an idea of how long ago a rock or artefact formed.

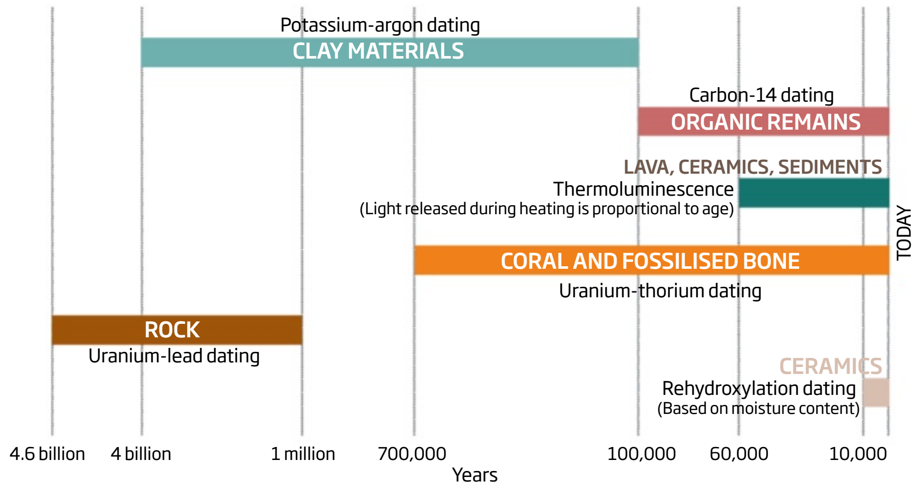
For most rocks, the favoured method is uranium-lead dating. Zircons are silicate minerals found in igneous rocks, and they often incorporate small impurities of uranium into their crystal structures. Two isotopes – uranium-238, with a half-life of some 4.5 billion years, and uranium-235 with a half-life of 704 million years – decay through two independent pathways, but both end on a stable isotope of lead. This produces a high level of accuracy. "It is widely regarded as the gold standard of dating," says Alan Dickin, a geologist at McMaster University in Hamilton, Ontario, Canada.

For younger rocks and prehistoric human artefacts, other isotopes provide more accurate results. The decay of potassium into argon has been used to date the first appearance of human tools in the Olduvai gorge in Tanzania to around 2 million years ago. The more substantial parts of human history since about 60,000 years ago, meanwhile, are written largely in the language of carbon isotopes. While the standard carbon-12 isotope is stable, a mutant form with two extra neutrons, carbon-14, has a half-life of 5730 years. Plants incorporate both forms through photosynthesis, and from there the isotopes proceed up the food chain. When an organism dies, the carbon-14 slowly decays away. It's useful for dating everything from desiccated plant seeds to ice-bound mammoths.

It's reassuring to know that, once we're six feet under, our bodies will keep the passage of time ticking. **Richard Webb** ■

Nature's clocks

The decay of natural isotopes can reveal the age of materials as far back as the formation of the solar system



NADÈGE MÉRIAU/MILLENNIUM IMAGES

Today... twice

TIME is money, so the saying goes, but these days the position of the hands on a clock face represents a good deal more than that. Clocks don't just tell us when to get up. Thanks to our reliance on GPS, they also help keep electricity flowing, our phones connected, and ships and planes on course.

Clocks also stir up plenty of strife. In fact the simple question "What's the time?" has become a source of passionate disagreement the world over.

Up until the 19th century, communities around the world were free to set their own local time. Then in 1876 a Scottish-born engineer called Sandford Fleming proposed standardising world time and dividing the globe into separate time zones. His concept of standard time formed the basis of the system adopted in 1884, but it took another 35 years before nations agreed a set of time zones covering the entire world. The result was 24 neat 15-degree wedges cutting smooth, longitudinal arcs down the Earth's surface, each marking a time shift of 1 hour.

No organisation was given ultimate authority over these zones. So in the years that followed, their smooth edges were tugged out of shape to suit geopolitical and commercial interests. Nowhere have these contortions been more pronounced than at the place where the sun (technically) rises on the planet: the international date line, which runs north to south down the Pacific.

Somewhere near the equator lies Kiribati, a nation that sprawls over 33 islands. As originally drawn, the international date line divides this island group, putting Tarawa, its capital, 25 hours ahead of the rest of Kiribati. This made it the only nation in the world in which the word "today" held two meanings.

In 1995, Kiribati took matters into its own hands and shifted its time-lagged eastern atolls and islands into tomorrow. This left a 3000-kilometre-long bulge in the international date line.

Not everyone was happy about it. Viewing the shift as a cynical ploy to pull in tourists for the approaching millennium celebrations, Kiribati's neighbour Fiji called the change "ridiculous". Samoa, which lies about 1200 kilometres to the south, went even further.

Samoans were already losing a full business day of communications each week – every Friday – with their major trading partners Australia and New Zealand, which were 21 hours ahead. Then came the Kiribati time shift, which served to further isolate the Samoans from their neighbours. So in 2011 Samoa engaged in some time travel of its own. The government decreed that at the end of the year Samoa would jump across the date line too, by dispensing with 30 December. As the clock struck midnight on 29 December the entire country time-travelled forward into New Year's Eve. The island of Tokelau, part of New Zealand, also made the jump that night.

While some cannot agree on what day it is, others get truly riled over a trifling 3600 seconds – specifically, the twice-yearly ritual of adding or subtracting an hour for "daylight saving". Struggles between supporters and opponents put all other disagreements over time zones in the shade.

Daylight saving time (DST) was introduced during the first world war, when Germany moved an hour of daylight from morning to evening as a fuel-saving measure. Other nations followed suit, and the practice was called up again during the next world war, at which point it became known as "war time".

The nomenclature proved prescient: its adoption has triggered numerous conflicts since 1945, including a riot at Ohio University in Athens in 1998, ›

10^5 10^6 10^7 10^8 10^9

Elephant pregnancy
22
months

Human lifetime
80
years

during which nearly 2000 students attacked police after learning that DST would lose them an hour of drinking time. Yet nowhere has it stirred up more bad blood than in the epicentre of time-zone brawling: the American state of Indiana.

Indiana sits astride the boundary between the central and eastern time zones, and since the late 1940s there has been passionate debate between city dwellers and those in rural areas over the adoption of daylight saving. Farmers, for example, object to DST since they lose morning light, while business owners argue that DST helps to smooth their dealings with commercial centres such as Chicago and New York.

To settle the matter, in 1972 a new law required counties in the eastern time zone to dispense with DST, while it became mandatory in the central time zone. Several counties ignored this and over the next 30 years, others attempted to throw off their time manacles. In the resulting climate of temporal uncertainty, long-distance bus timetables were a riddle and some children could expect to arrive at school before they left home, while their parents would need to allot 90 minutes for a half-hour commute.

When state-wide DST was finally adopted in 2006, Indiana's governor Mitch Daniels was unequivocal: "Nothing will ever be more confusing than the world we're leaving behind," he promised.

Perhaps. Yet Indianans love fisticuffs so much that they are rallying to a new cause. A disparate group calling itself the Central Time Coalition is now demanding that the entire state be moved, lock stock and barrel, on to central time. The real mystery is how Indiana's clock campaigners find a moment to get anything done. **Sally Adee** ■

10^{10} 10^{11} 10^{12} 10^{13} 10^{14}

Era of Homo sapiens

200,000 years

BJANKA KADIC/MILLENNIUM IMAGES

Time travel

IT IS easy to dismiss time travel as nothing more than science fiction. After all, H.G. Wells wrote *The Time Machine* in the late 1800s, but still no one has built one that works. Don't give up yet, though: we are continuing to make discoveries that may show us the way forward – or back.

Time travel is inherent in the basics of general relativity. Einstein's theory predicts that time runs more slowly in strong gravity, so you grow old more slowly living in a bungalow than in a skyscraper: being closer to the ground, you are in marginally stronger gravity (see "Personal time warps", page 86). So to make a time machine, you simply have to connect two regions where time flows at different rates.

Take, for instance, the Earth and the immediate vicinity of a black hole, where strong gravity makes time flow extremely slowly. Say you start two clocks ticking on Monday at the two locations. When Friday comes around on Earth, it will still be only Wednesday by the black hole. So if you could travel instantaneously from Earth to near the black hole, you could travel from Friday back to Wednesday. Hey presto: time travel.

The question is, can you? Yes – in principle. According to quantum theory, the fabric of space-time is a tangle of sub-microscopic shortcuts through space and time known as wormholes. A few steps along such a tunnel and you might emerge light years away on the other side of the galaxy, or years in the past or future.

However, there are a few practical problems to sort out first. To use a wormhole for time travel, it has to link the times and places you want to travel between: that might mean somehow towing one end to the nearest black hole.

Manage that and you've still got issues: you would need to inflate the quantum-scale wormhole to macroscopic size and find a way to keep its entrance and exit open. Quite some challenge, because wormholes are terminally unstable and snap shut in the blink of an eye. To prop them open, you will need a hypothetical type of matter with repulsive gravity. We do not know whether such exotic matter with sufficient strength exists. But what we do know is that to create a tunnel with a mouth about a metre across – wide enough for someone to crawl through – you would have to use the total energy pumped out by a large fraction of the stars in our Milky Way in a year.

For all that effort, such a time machine

"If you want to go on a dinosaur safari, you'll need to find a time machine left by aliens at least 65 million years ago"

will never take us back to great moments in history. If we find a wormhole, it is by definition the first moment that time travellers to the past will be able to reach. So if you want to go on a dinosaur safari, you have only one option: find a time machine abandoned on Earth by extraterrestrials at least 65 million years ago.

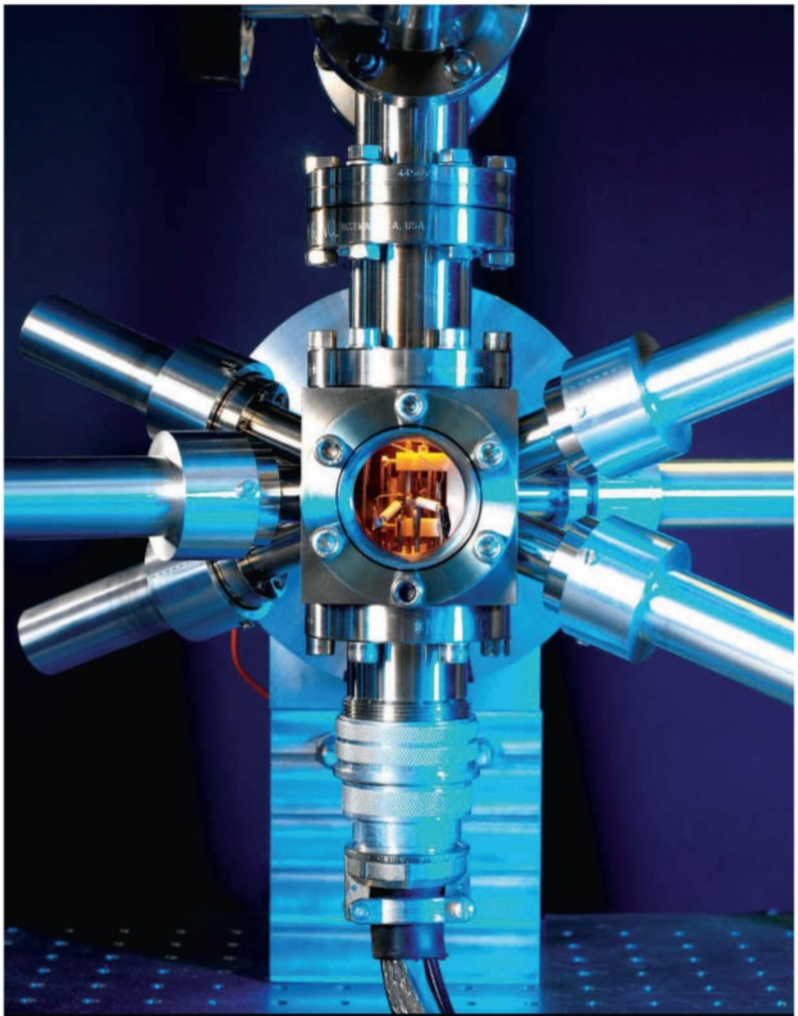
Nonetheless, we could do some interesting things with our own time machine. As soon as we have made one, for instance, future civilisations will be able to come back and visit us. That opens up an interesting possibility: could someone come back and kill a direct ancestor, making their own existence impossible? This is time travel's most famous conceptual puzzle, the "grandfather paradox". And it turns out that quantum physics may have an answer.

For years now, quantum physicists have been "teleporting" particles by copying the information that describes a particle and pasting it on to another, distant one. In 2009, Seth Lloyd of the Massachusetts Institute of Technology and Aephraim Steinberg of the University of Toronto, Canada, showed that quantum rules allow this kind of teleportation to be done in time as well as space. Because the quantum states of particles such as photons and electrons can be affected by measurements that will be done in their futures, time travel comes naturally to the quantum world. They then proved it by sending a photon a few billionths of a second back in time.

Lloyd and Steinberg's experiments showed that, with photons at least, the mechanics of time travel conspire to uphold familiar notions of cause and effect. They set up photons to travel backwards in time and then flip their polarisation state. This flip corresponded to the photon entering a state that meant it could not have travelled back in time in the first place; the new state "kills" the earlier one.

Because of the probabilities involved in quantum measurements there was always a chance of either process failing to happen. Lloyd and Steinberg found that when they set up the photon to kill its "grandfather", either the time travel or the polarisation flip always failed.

It's an example of what Stephen Hawking at the University of Cambridge calls chronology protection. As the difficulty of creating a wormhole time machine also shows, the laws of physics seem determined to maintain common-sense rules of cause and effect. Nonetheless, the door to time travel is still firmly open. **Marcus Chown** ■



ANDREW BROOKES/NPL/SPL

The ultimate clock

SINCE 1955, when Louis Essen and Jack Parry of the UK's National Physical Laboratory (NPL) in Teddington demonstrated the first atomic clock – capable of keeping time to an accuracy of 0.0001 seconds per day – clocks precise to even more trifling fractions of a second have brought the world ever more in sync.

Today, the second is defined by a number – 9,192,631,770 to be exact – of atomic transitions in an atom of caesium-133 at absolute zero.

The record for the most accurate timepiece swings back and forth between the world's national standards labs. In 2010 it was reclaimed by the NPL with its NPL-CsF2 clock, which works by tossing a fountain of caesium atoms upwards and measuring their transitions on the way up and down to counterbalance the effects of gravity. Had it been ticking since the dinosaurs died out 65 million years ago, the clock would have lost or gained only about half a second.

Three years later, however, the record was retaken by the US National Institute of Standards and Technology in Boulder, Colorado. It built a pair of clocks based on the oscillations of ytterbium atoms that it says is an order of magnitude more accurate. The most precise clock possible? Only time will tell. Richard Webb ■

The end of time

WILL time end? It is a disturbing prospect, more chilling even than the end of our universe, because in most of the ordinary scenarios of cosmic doom there remains the comforting possibility that a new universe might rise from the ashes of the old (see page 35).

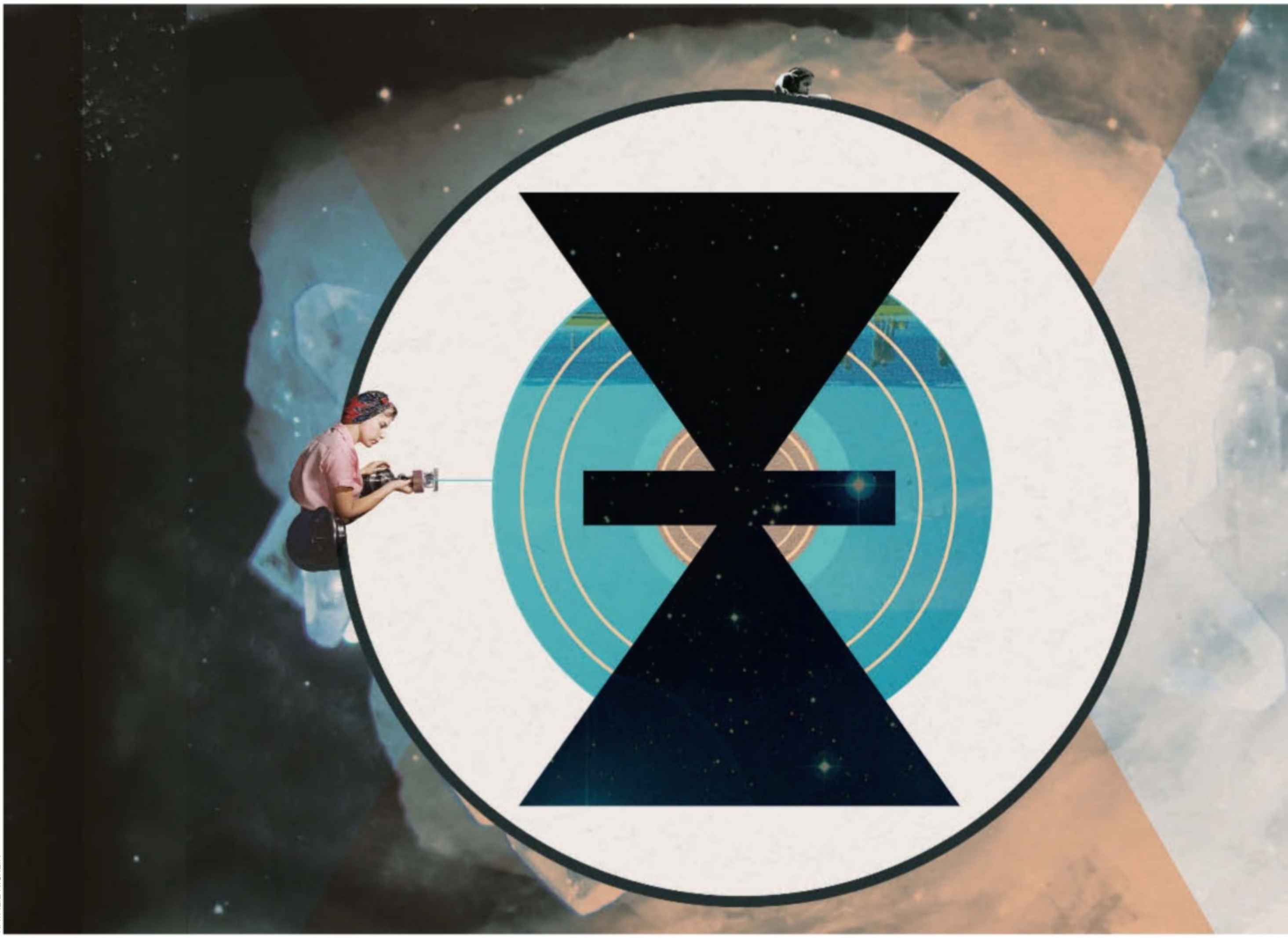
But if time itself can end, then we surely have no get-out clause. There will be no time for anything new to get started. That will be that.

In recent years, cosmologists have been trying to face this final curtain. Perhaps it is not such a grisly proposition for them, as they are already used to the many ends of time that come out of Einstein's general theory of relativity. This gravitational theory implies that when a star collapses into a black hole, its matter is crushed to a single point of infinite density called a singularity, a full stop where all quantities become infinite and time ends.

You could go and see what it is like by heading for the nearest black hole and jumping in, something we might all get to enjoy if the universe ends in a "big crunch" and everything collapses down to one cosmic singularity.

General relativity is probably not an exact theory, however, and physicists suspect that its perfectly point-like singularities will be blurred out slightly by the effects of quantum mechanics. If that is the case, when space-time goes through the mangle of a black hole or big crunch there may be enough room for it to survive and bounce back on the other side.

Having escaped a violent end, time might simply coast to a halt. One of the distinctive things about time is that it only points one way, heading from past to future. This directionality stems from the fact that the known universe used to be super-dense (see "Time's arrow", page 90). When everything was neatly tucked away in one spot, it was

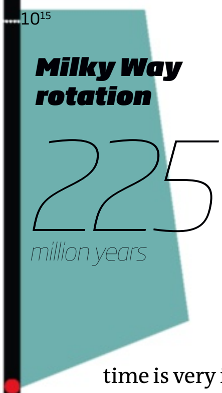


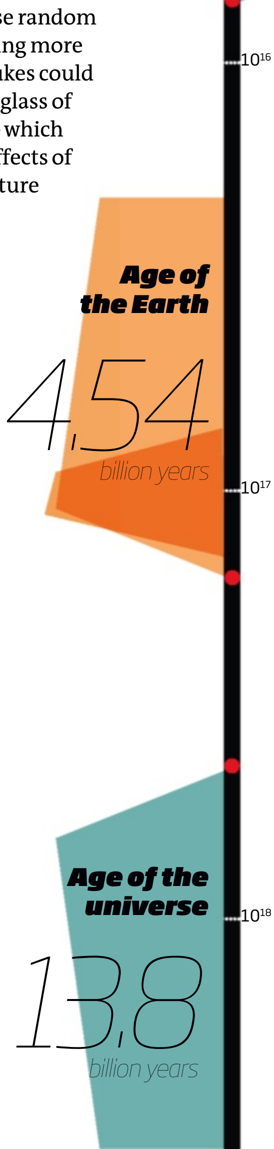
NATALIE NICKLIN

in a highly ordered state, but as space expanded everything was free to become more disorderly.

After countless trillions of years, when all the stars have burned out and even the black holes have evaporated, all matter in our universe may become evenly spread out. Everything will be as disordered as it can possibly be. Then there will be no direction to time, and not much happening either.

On a subatomic scale, however, particles will still be colliding with one another and occasionally these random collisions will lead to something more interesting. Rare statistical flukes could produce an ordered object – a glass of beer, say, or a puzzled lemur – which will briefly be subject to the effects of time once more. So in this picture time is very ill, but it is not quite dead.





Time's true demise may be decreed by the multiverse. Many models of the cosmos involve a form of expansion called eternal inflation, in which new universes are constantly being created, each with different properties. Cosmologists want to get a handle on the range of possibilities – how many of these universes have stars, how many have matter, what proportion is hospitable to life – but they have hit a snag. In an infinitely multiplying universe there is an infinite number of versions of everything, and it becomes impossible to calculate probabilities.

To get around this, some cosmologists pretend that most of the multiverse doesn't exist. By imposing an arbitrary cut-off in space and time, they can calculate probabilities for our local patch of the multiverse. It seems to work. For example, they use this to predict a value for the cosmological constant – the repulsive force that boosts the expansion of the universe – that's in the same ballpark as that measured by astronomers.

While that sounds like good news for cosmologists and their calculations, it is bad news for time. Raphael Bousso of the University of California, Berkeley, has pointed out that these probabilities are only consistent if the real multiverse is finite in time. If the cut-off multiverse reflects reality, he calculates that time probably only has a few billion years left. "It's a crazy-sounding proposition, but in physics one has to be careful ruling things out just because they seem crazy," he says.

Time has the right to ask for a second opinion, in the hope of a better prognosis. In 2011 Alan Guth of the Massachusetts Institute of Technology and Vitaly Vanchurin, now of the University of Minnesota in Duluth, calculated probabilities in the multiverse without having to decapitate time. They still did not rule out the possibility, however.

If such an End of Ends is possible, what will it look like? Igor Smolyaninov at the University of Maryland in College Park has done an experiment to find out. As a stand-in for the universe, he used a material made from stripes of plastic deposited onto a film of gold, which bends light in a peculiar way. In this metamaterial, one axis acts like time drawing light rays inevitably onwards – a motion mathematically identical to light moving in space-time.

Smolyaninov joined some of this metamaterial to a piece of ordinary material where light can move freely in any direction, meaning there is no axis of time. He found that at the boundary between the two realms, where "time runs out", light piles up to create a powerful electric field. Theory predicts that without energy losses in the material, the electric field would increase to infinity.

"Our physical vacuum probably behaves like a metamaterial, so our experiments probably make some sense," says Smolyaninov. If the analogy holds, then in real space all energy fields would be boosted to huge values, raising the temperature and filling the last split second of existence with an inferno of particle creation. If you think everything is going to hell, maybe you are right.

A more serene vision of the end comes from Julian Barbour, a philosopher who has collaborated with cosmologists in building a peculiar picture of reality that he calls Platonia. In Platonia, all possible configurations of matter exist. There is no passage of time, merely a set of unconnected instants, or "nows". We experience the illusion of time because many of these nows are arranged as if they had evolved through time. Barbour thinks that the possibilities in Platonia should be infinite, and so the comforting illusion of time should be infinite too. If time doesn't exist, it won't end.

"Prediction is difficult," said physicist Niels Bohr, "especially about the future." So perhaps it's not surprising that there is no last word on the end of time. **Stephen Battersby** ■

CHAPTER SEVEN

THE SELF

As you wake up each morning, hazy and disoriented, you gradually become aware of the rustling of the sheets, sense their texture and squint at the light. One aspect of your self has reassembled: the first-person observer of reality, inhabiting a human body.

As wakefulness grows, so does your sense of having a past, a personality and motivations. Your self is complete, as both witness of the world and bearer of your consciousness and identity. You.

This intuitive sense of self is an effortless and fundamental human experience. But it is nothing more than an elaborate illusion. Under scrutiny, many common-sense beliefs about selfhood begin to unravel. Some thinkers even go as far as claiming that there is no such thing as the self.

You are not the person you thought you were.

DARREN HOPES

WHAT ARE YOU?

Our intuitive beliefs about ourselves are easily demolished, says **Jan Westerhoff**

THERE appear to be few things more certain to us than the existence of our selves. We might be sceptical about the existence of the world around us (see page 9), but how could we be in doubt about the existence of us? Isn't doubt made impossible by the fact that there is somebody who is doubting something? Who, if not us, would this somebody be?

While it seems irrefutable that we must exist in some sense, things get a lot more puzzling once we try to get a better grip of what having a self actually amounts to.

Three beliefs about the self are absolutely fundamental for our belief of who we are. First, we regard ourselves as unchanging and continuous. This is not to say that we remain forever the same, but that among all this change there is something that remains constant and that makes the "me" today the same person I was five years ago and will be five years in the future.

Second, we see our self as the unifier that brings it all together. The world presents itself to us as a cacophony of sights, sounds, smells, mental images, recollections and so forth. In the self, these are all integrated and an image of a single, unified world emerges.

Finally, the self is an agent. It is the thinker of our thoughts and the doer of our deeds. It is where the representation of the world, unified into one coherent whole, is used so we can act on this world.

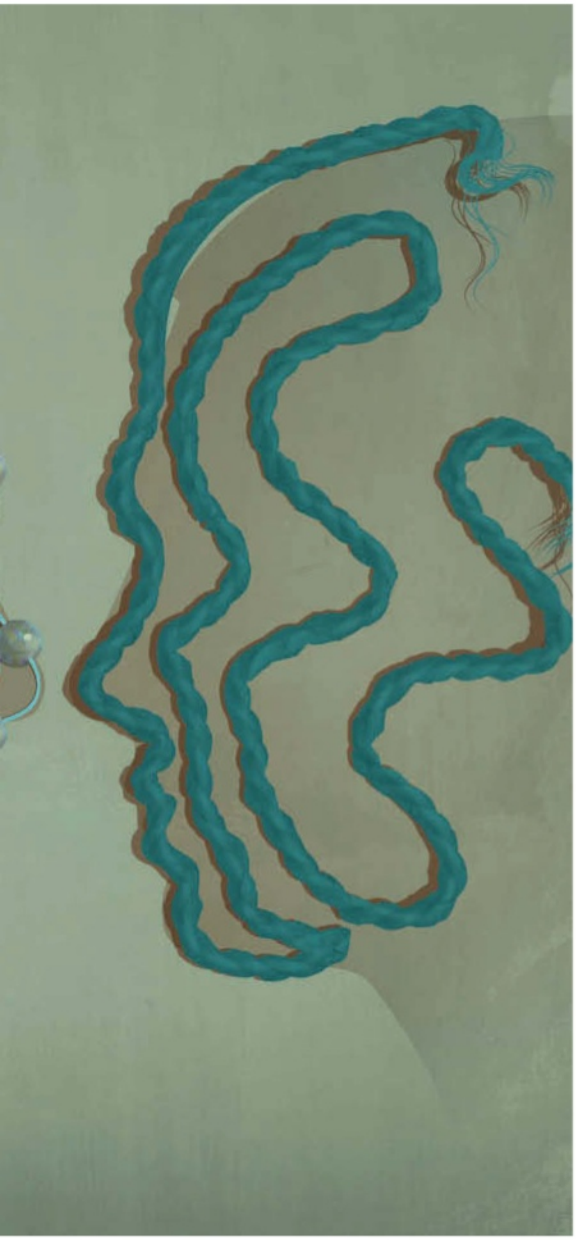
All of these beliefs appear to be blindingly obvious and as certain as can be. But as we look at them more closely, they become less and less self-evident.

It would seem obvious that we exist continuously from our first moments in our mother's womb up to our death. Yet during the time that our self exists, it undergoes substantial changes in beliefs, abilities, desires and moods. The happy self of yesterday cannot be exactly the same as the grief-stricken self of today, for example. But we surely still have the same self today that we had yesterday.

There are two different models of the self we can use to explore this issue: a string of pearls and a rope. According to the first model, our self is something constant that has all the changing properties but remains itself unchanged. Like a thread running through every pearl on a string, our self runs through every single moment of our lives, providing a core and a unity for them. The difficulty with this view of the self is that it cannot be most of the things we usually think define us. Being happy or sad, being able to speak Chinese, preferring cherries to strawberries, even being conscious – all these are changeable states, the disappearance of which should not affect the self, as a disappearance of individual pearls should not affect the thread. But it then becomes unclear why such a minimal self should have the central status in our lives that we usually accord to it.

"OUR SELF RUNS THROUGH OUR LIVES LIKE A THREAD RUNS THROUGH A STRING OF PEARLS"

The second model is based on the fact that a rope holds together even though there is no single fibre running through the entire rope, just a sequence of overlapping shorter fibres. Similarly, our self might just be the continuity of overlapping mental events. While this view has a certain plausibility, it has problems of its own. We usually assume that when we think of something or make a decision, it is the whole of us doing it, not just some specific part. Yet, according to the rope view, our self is never completely present at any point, just like a rope's threads do not run its entire length.



DARREN HOPES

I am the one and only

Think back to your earliest memory. Now project forward to the day of your death. It is impossible to know when this will come, but it will.

What you have just surveyed might be called your "self-span", or the time when this entity you call your self exists. Either side of that, zilch.

Which is very mysterious, and a little unsettling. Modern humans have existed for perhaps 100,000 years, and more than 100 billion have already lived and died (see page 119). We assume that they all experienced a sense of self similar to yours. None of these selves has made a comeback, and as far as we know, neither will you.

What is it about a mere arrangement of matter and energy that gives rise to a subjective sense of self? It must be a collective property of the neurons in your brain, which have mostly stayed with you throughout life, and which will cease to exist after you die. But why a given bundle of neurons can give rise to a given sense of selfhood, and whether that subjective sense can ever reside in a different bundle of neurons, may forever remain a mystery. **Graham Lawton**

It seems then as if we are left with the unattractive choice between a continuous self so far removed from everything constituting us that its absence would scarcely be noticeable, and a self that actually consists of components of our mental life, but contains no constant part we could identify with. The empirical evidence we have so far points towards the rope view, but it is by no means settled.

Even more important, and just as troublesome, is our second core belief about the self: that it is where it all comes together.

It is easy to overlook the significance of this fact, but the brain accomplishes an extremely complex task in bringing about the appearance of a unified world. Consider, for example, that light travels much faster than sound yet visual stimuli take longer to process than noises. Putting together these different speeds means that sights and sounds from an event usually become available to our consciousness at different times (only sights and sounds from events about 10 metres away are available at the same time). That means the apparent simultaneity of hearing a voice and seeing the speaker's lips move, for example, has to be constructed by the brain.

Our intuitive view of the result of this process resembles a theatre. Like a spectator seated in front of a stage, the self perceives a unified world put together from a diverse range of sensory data. It would get confusing if these had not been unified in advance, just as a theatregoer would be confused if they heard an actor's lines before he was on stage. While this view is persuasive, it faces many difficulties.

> "THE SELF IS NOT ONLY A USEFUL ILLUSION, IT MAY ALSO BE A NECESSARY ONE"

Consider a simple case, the "beta phenomenon". If a bright spot is flashed onto the corner of a screen and is immediately followed by a similar spot in the opposite corner, it can appear as if there was a dot moving diagonally across the screen. This is easily explained: the brain often fills in elements of a scene using guesswork. But a tweak to this experiment produces a curious effect.

If the spots are different colours – for example a green spot followed by a red spot – observers see a moving spot that changes colour abruptly around the mid-point of the diagonal (see "Spotted trick", page 98). This is very peculiar. If the brain is filling in the missing positions along the diagonal for the benefit of the self in the theatre, how does it know before the red spot has been observed that the colour will switch?

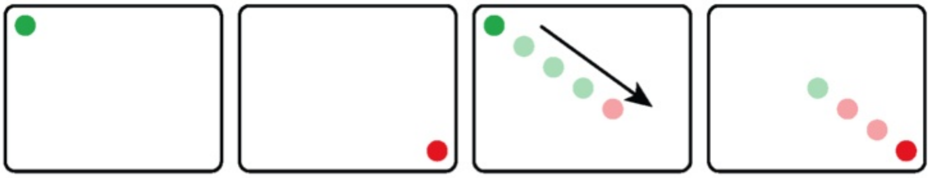
One way of explaining the beta phenomenon is by assuming that our experience is played out in the theatre with a small time delay. The brain doesn't pass on the information about the spots as soon as it can, but holds it back for a little while. Once the red spot has been processed, both spots are put together into a perceptual narrative that involves one moving spot changing colour. This edited version is then screened in the theatre of consciousness.

Unfortunately, this explanation does not fit in well with evidence of how perception works. Conscious responses to visual stimuli can occur at a speed very close to the minimum time physically possible. If we add up the time it takes for information to reach the brain and then be processed, there is not enough time left for a delay of sufficient length to explain the beta phenomenon.

Perhaps there is something wrong with the notion of a self perceiving a unified stream of sensory information. ›

Spotted trick

If two dots are flashed on a screen in quick succession, the brain creates the illusion of a phantom dot moving between – and if the colours of the dots are different, the result is even stranger



When two coloured dots are flashed in quick succession…

…some people report a ghost dot moving between them that changes colour abruptly along the way

The weird thing is, people report seeing the colour change to red BEFORE the red dot has even appeared

Perhaps there are just various neurological processes taking place in the brain and various mental processes taking place in our mind, without some central agency where it all comes together at a particular moment, the perceptual "now" (see "When are you?", page 99). It is much easier to make sense of the beta phenomenon if there is no specific time when perceptual content appears in the theatre of the self – because there is no such theatre.

The perception of a green spot turning red arises in the brain only after the perception of the red spot. Our mistaken perception of the real flow of events is akin to the way we interpret the following sentence: "The man ran out of the house, after he had kissed his wife". The sequence in which the information comes in on the page is "running–kissing", but the sequence of events you construct and understand is "kissing–running". For us to experience events as happening in a specific order, it is not necessary that information about these events enters our brain in that same order.

The final core belief is that the self is the locus of control. Yet cognitive science has shown in numerous cases that our mind can conjure, post hoc, an intention for an action that was not brought about by us.

In one experiment, a volunteer was asked to move a cursor slowly around a screen on which 50 small objects were displayed, and asked to stop the cursor on an object every 30 seconds or so.

Self-delusion

The computer mouse controlling the cursor was shared, ouija-board style, with another volunteer. Via headphones, the first volunteer would hear words, some

of which related to the objects on screen. What this volunteer did not know was that their partner was one of the researchers who would occasionally force the cursor towards a picture without the volunteer noticing.

If the cursor was forced to the image of a rose, and the volunteer had heard

When the self breaks

For most people, most of the time, the sense of self is seamless and whole. But as with any construct of the brain, it can be profoundly disturbed by illness, injury or drugs. **Anil Ananthaswamy** and **Graham Lawton** reveal a few examples

Depersonalisation Disorder

Many people experience occasional feelings of detachment from reality, but for others "depersonalisation" is an everyday part of life. *The Diagnostic and Statistical Manual of Mental Disorders IV* defines it as "a feeling of detachment or estrangement from one's self… The individual may feel like an automaton or as if he or she is living in a dream or a movie. There may be a sensation of being an outside observer of one's mental processes, one's body, or parts of one's body."

It is not clear what causes depersonalisation, but there is some evidence linking it to a malfunction of the emotion systems.

The petrified self

A crucial building block of selfhood is the autobiographical self, which allows us to recall the past, project into the future and view ourselves as unbroken entities across time. Key to this is the formation of memories of events in our lives.

Autobiographical memory formation is one of the first cognitive victims of Alzheimer's disease. This lack of new memories, along with the preservation of older ones, may be what leads to the outdated sense of self – or "petrified self" – often seen in people in the early stages of the disease. It could also be what causes a lack of self-awareness of having the illness at all.

Continued on page 101

ERIC FLOGNY/ALEPH/PICTURETANK

the word "rose" a few seconds before, they reported feeling that they had intentionally moved the mouse there. The reasons why these cues combined to produce this effect is not what is interesting here: more important is that it reveals one way that the brain does not always display its actual operations to us. Instead, it produces a post-hoc "I did this" narrative despite lacking any factual basis for it.

So, many of our core beliefs about ourselves do not withstand scrutiny. This presents a tremendous challenge for our everyday view of ourselves, as it suggests that in a very fundamental sense we are not real. Instead, our self is comparable to an illusion – but without anybody there that experiences the illusion.

Yet we may have no choice but to endorse these mistaken beliefs. Our whole way of living relies on the notion that we are unchanging, coherent and autonomous individuals. The self is not only a useful illusion, it may also be a necessary one. ■

WHEN ARE YOU?

You are being tricked into thinking you live in the present, says **Jan Westerhoff**

IT SEEMS obvious that we exist in the present. The past is gone and the future has not yet happened, so where else could we be? But perhaps we should not be so certain.

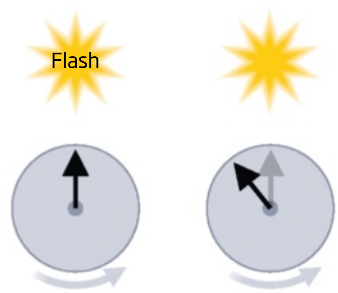
Sensory information reaches us at different speeds, yet appears unified as one moment. Nerve signals need time to be transmitted and time to be processed by the brain. And there are events – such as a light flashing, or someone snapping their fingers – that take less time to occur than our system needs to process them. By the time we become aware of the flash or the finger-snap, it is already history.

Our experience of the world resembles a television broadcast with a time lag; conscious perception is not "live". This on its own might not be too much cause for concern, but in the same way the TV time lag makes last-minute censorship possible, our brain, rather than showing us what happened a moment ago, sometimes constructs a present that has never actually happened.

Evidence for this can be found in the "flash-lag" illusion. In one version, a screen displays a rotating disc with an arrow on it, pointing outwards (see "Now you see it…", below). Next to the disc is a spot of light that is programmed to flash at the exact moment the spinning arrow passes it. Yet this is not what we perceive. Instead, the flash lags behind, apparently occurring after the arrow has passed.

Now you see it…

In this flash-lag illusion, a spinning arrow and flashing spot are programmed to coincide precisely in time – but that's not what we see



One explanation is that our brain extrapolates into the future. Visual stimuli take time to process, so the brain compensates by predicting where the arrow will be. The static flash – which it can't anticipate – seems to lag behind.

Neat as this explanation is, it cannot be right, as was shown by a variant of the illusion designed by David Eagleman of Baylor College of Medicine in Houston, Texas, and Terrence Sejnowski of the Salk Institute for Biological Studies in La Jolla, California.

If the brain were predicting the spinning arrow's trajectory, people would see the lag even if the arrow stopped at the exact moment it was pointing at the spot. But in this case the lag does not occur. What's more, if the arrow starts stationary and moves in either direction immediately after the flash, the movement is perceived before the flash. How can the brain predict the direction of movement if it doesn't start until after the flash?

The explanation is that rather than extrapolating into the future, our brain is interpolating events in the past, assembling a story of what happened retrospectively. The perception of what is happening at the moment of the flash is determined by what happens to the disc after it. This seems paradoxical, but other tests have confirmed that what is perceived to have occurred at a certain time can be influenced by events that happen later.

All of this is slightly worrying if we hold on to the common-sense view that our selves are placed in the present. If the moment in time we are supposed to be inhabiting turns out to be a mere construction, the same is likely to be true of the self existing in that present. ■

WHERE ARE YOU?

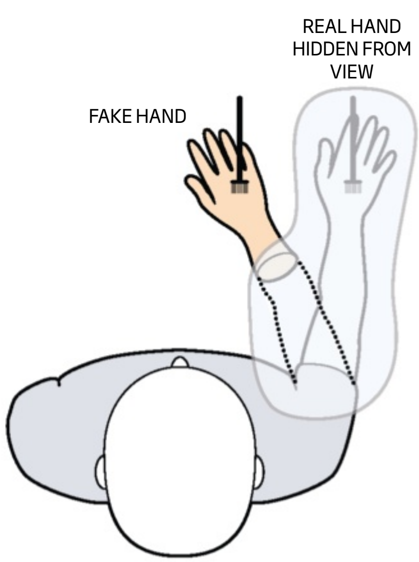
Your self feels anchored in your body, but it's surprisingly flexible, says **Anil Ananthaswamy**

CLOSE your eyes and ask yourself: where am I? Not geographically, but existentially. Most of the time, we would say that we are inside our bodies. After all, we peer out at the world from a unique, first-person perspective within our heads – and we take it for granted.

We wouldn't be so sanguine if we knew that this feeling of inhabiting a body is something the brain is constantly constructing. But the fact that we live inside our bodies doesn't mean that our sense of self is confined to its borders – as these next examples show.

Get out of hand

Stroke someone's hand while they watch a rubber hand being stroked in the same way, and the contours of their self shift to include the fake hand instead



Sleight of (rubber) hand

By staging experiments that manipulate the senses, we can explore how the brain draws – and redraws – the contours of where our selves reside.

One of the simplest ways to see this in action is via an experiment that's now part of neuroscience folklore: the rubber hand illusion. The set up is simple: a person's hand is hidden from their view by a screen while a rubber hand is placed on the table in front of them. By stroking their hand while they see the rubber hand being stroked, you can make them feel that the fake hand is theirs (see diagram, below left).

Why does this happen? The brain integrates various senses to create aspects of our bodily self. In the rubber hand illusion, the brain is processing touch, vision and proprioception – the internal sense of the relative location of our body parts. Given the conflicting information, the brain resolves it by taking ownership of the rubber hand.

The implication is that the boundaries of the self sketched out by the brain can easily expand to include a foreign object. And the self's peculiar meanderings outside the body don't end there.

Trading places

Ever wish you had someone else's body? The brain can make it happen. To show how, Henrik Ehrsson at the Karolinska Institute in Stockholm, Sweden, and colleagues transported people out of their own bodies and into a life-size mannequin.

The mannequin had cameras for eyes, and whatever it was "seeing" was fed into a head-mounted display worn by a volunteer. In this case, the mannequin's gaze was pointed down at its abdomen. When the researchers stroked the ›

DARREN HOPES

When the self breaks

Body Integrity Identity Disorder

Imagine a relentless feeling that one of your limbs is not your own. That is the unenviable fate of people with body integrity identity disorder. They often feel it so intensely that they end up amputating the "foreign" part.

The disorder can be viewed as a perturbation of the bodily self caused by a mismatch between the internal map of one's own body and physical reality. Neuroimaging studies by Peter Brugger of University Hospital Zurich in Switzerland have shown that the network of brain regions responsible for creating a sense of bodily self is different in people with the condition.

Psychedelics

One of the most reliable – and reversible – ways to alter your sense of self is to ingest psychedelic drugs such as LSD or psilocybin, the active ingredient in magic mushrooms.

Alongside sensory distortions such as visual hallucinations, a common psychedelic experience is a feeling that the boundary between one's self and the rest of the world is dissolving. A team led by David Nutt of Imperial College London recently discovered why: psilocybin causes a reduction in activity in the anterior cingulate cortex, a part of the brain thought to be involved in integrating perception and the sense of self. It was assumed that psychedelics worked by increasing brain activity; it seems the opposite is true.

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abdomens of both the volunteer and the mannequin at the same time, many identified with the mannequin's body as if it was their own.

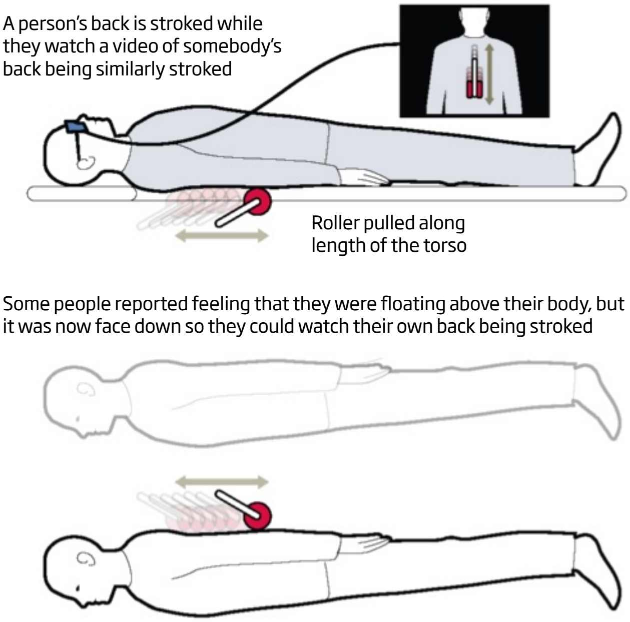
In 2011, the team repeated the experiment, but this time while monitoring the brain activity of volunteers lying in an fMRI scanner. They found that activity in certain areas of the frontal and parietal lobes correlated with the changing sense of body ownership.

So what's happening? Studies of macaque monkeys show that these brain regions contain neurons that integrate vision, touch and proprioception. Ehrsson thinks that in the human brain such neurons fire only when there are synchronous touches and visual sensations in the immediate space around the body, suggesting that they play a role in constructing our sense of body ownership. Mess with the information the brain receives, and you can mess with this feeling of body ownership.

Yet while Ehrsson's study manipulated body ownership, the person "inside" the mannequin still had a first-person perspective – their self was still located within a body, even if it wasn't their own. Could it be possible to wander somewhere where there is no body at all?

Leaving the body

By manipulating the way the brain integrates the senses, some people can be induced to feel they are floating above their body



"MOST VOLUNTEERS FELT THEY WERE FLOATING; A FEW EXPERIENCED A PARTICULARLY STRANGE SENSATION"

Into thin air

Your self even can be tricked into leaving your body and hovering in mid-air above it.

In 2011, Olaf Blanke at the Swiss Federal Institute of Technology in Lausanne and colleagues asked volunteers to lie on their backs and, via a headset, watch a video of a person of similar appearance being stroked on the back. Meanwhile, a robotic arm installed within the bed stroked the volunteer's back in the same way.

The experience that people described was significantly more immersive than simply watching a movie of someone else's body. Most volunteers felt they were floating above their own body and a few experienced a particularly strange sensation. Despite the fact that they were all lying facing upwards, some felt they were floating face down so they could watch their own back (see "Leaving the body", left).

"I was looking at my own body from above," said one participant. "The perception of being apart from my own body was a bit weak but still there."

"That was for us really exciting, because it gets really close to the classical out-of-body experience of looking down at your own body," says team member Bigna Lenggenhager, now at the University of Zurich in Switzerland.

Further support came by repeating the experiment inside an MRI scanner, which showed a brain region called the temporoparietal junction (TPJ) behaving differently when people said they were drifting outside their bodies. This corresponds neatly with previous studies of people with brain injuries who reported out-of-body experiences, which have also implicated the TPJ.

The TPJ shares a common trait with other brain regions that researchers believe are associated with body illusions: it helps to integrate visual, tactile and proprioceptive senses with the signals

ERIC FLOGNY/ALEPH/PICTURETANK

from the inner ear that give us our sense of balance and spatial orientation. This provides more evidence that the brain's ability to integrate various sensory stimuli plays a key role in locating the self in the body.

According to philosopher Thomas Metzinger of the Johannes Gutenberg University in Mainz, Germany, understanding how the brain performs this trick is the first step to understanding how the brain puts together our autobiographical self – the sense we have of ourselves as entities that exist from a remembered past to an imagined future.

"These experiments are very telling, because they manipulate low-level dimensions of the self: self-location and self-identification," he says.

The feeling of owning and being in a body is perhaps the most basic facet of self-consciousness, and so could be the foundation on which more complex aspects of the self are built. The body, it seems, begets the self. ■

WHY ARE YOU?

You're so vain, you probably think your self is about you, says **Michael Bond**

THE first time a baby smiles, at around 2 months of age, is an intense and beautiful moment for the parents. It is perhaps the first sure sign of recognition for all their love and devotion. It might be just as momentous for the baby, representing their first step on a long road to identity and self-awareness.

Identity is often understood to be a product of memory as we try to build a narrative from the many experiences of our lives. Yet there is now a growing recognition that our sense of self may be a consequence of our relationships with others. "We have this deep-seated drive to interact with each other that helps us discover who we are," says developmental psychologist Bruce Hood at the University of Bristol, UK, author of *The Self Illusion*. And that process starts not with the formation of a child's first memories, but from the moment they first learn to mimic their parents' smile and to respond empathically to others.

The idea that the sense of self drives, and is driven by, our relationships with others makes intuitive sense. "I can't have a relationship without having a self," says Michael Lewis, who studies child development at the Robert Wood Johnson Medical School in New Brunswick, New Jersey. "For me to interact with you, I have to know certain things about you, and the only way I can get at those is by knowing things about me."

There is now evidence that this is the way the brain works. Some clues come from people with autism. Although the disorder is most commonly associated with difficulties in understanding other people's non-verbal social cues, it also seems to create some problems with self-reflection: when growing up, people with autism are later to learn how to recognise themselves in a mirror and tend to form fewer autobiographical memories. Tellingly, the same brain regions – ›

FLORE-AEL SURUN/TENDANCE FLOUE

When the self breaks

Cotard's delusion

Of all the disturbances of the self, the eeriest and least understood is Cotard's delusion. Symptoms of this rare syndrome range from claims that one's blood or internal organs have gone missing to a belief that one is dead or has otherwise ceased to exist. People with the delusion – who are often severely depressed or psychotic – have been known to plan their own funerals.

SCOTIA LUHRS/MILLENNIUM IMAGES, UK

"I'M AN ACADEMIC, I'M MARRIED. ALL OF THESE THINGS THAT I DEFINE MYSELF AS ARE REALLY CULTURAL ARTEFACTS"

ERIC FLOGNY/ALEPH/PICTURETANK

areas of the prefrontal cortex – seem to show reduced activity when autistic people try to perform these kinds of tasks, and when they try to understand another's actions. This supports the idea that the same brain mechanism underlies both types of skills.

Further support for the idea comes from the work of Antonio Damasio at the University of Southern California, who has found that social emotions such as admiration or compassion, which result from a focus on the behaviour of others, tend to activate the posteromedial cortices, another set of brain regions also thought to be important in constructing our sense of self.

The upshot is that my own self is not so much about me; it's as much about those around me and how we relate to one another – a notion that Damasio calls "the social me". This has profound implications. If a primary function of self-identity is to help us build relationships, then it follows that the nature of the self should depend on the social environment in which it develops. Evidence for this comes from cultural psychology. In his book *The Geography of Thought*, Richard Nisbett at the University of Michigan in Ann Arbor presented lab experiments suggesting that Chinese and other east Asian people tend to focus on the context of a situation, whereas Westerners analyse phenomena in isolation – different outlooks that affect the way we think about ourselves.

Researchers examining autobiographical memory, for example, have found that Chinese people's recollections are more likely to focus on moments of social or historical significance, whereas people in Europe and America focus on personal interest and achievement. Other studies of identity, meanwhile, have found that Japanese people are more inclined to tailor descriptions of themselves depending on the situation at hand, suggesting they have a more fluid, less concrete sense of themselves than Westerners, whose accounts tend not to rely on context in this way.

Such differences may emerge at an early age. Lewis points to anthropological reports suggesting that the "terrible twos" – supposedly the time when a child develops an independent will – are not as dramatic in cultures less focused on individual autonomy, which would seem to show that culture sculpts our sense of self during our earliest experiences.

These disparities in outlook and thinking imply that our very identities – "what it is that I am" – are culturally determined. "I'm a male, I'm an academic, I'm a senior, I'm married, I'm a father and grandfather: all of these things that I define myself as are really cultural artefacts," says Lewis. Clearly there is no single pan-cultural concept of selfhood.

VINCENT MIGEAT/AGENCE VU/CAMERA PRESS

Yet Hazel Markus, who studies the interaction of culture and self at Stanford University in California, points out that human personalities do share one powerful trait: the capacity to continually shape and be shaped by whatever social environment we inhabit.

While the evidence for "the social me" continues to mount, not everyone is convinced that it is always helpful for our well-being. To the writer and psychologist Susan Blackmore, the self may be a by-product of relationships. It may simply unfold "in the context of social interaction and learning to relate to others, which may inevitably lead you to this sense that I am in here" while bringing some unfortunate baggage along with it. She points out that the self can compel us to cling neurotically to emotions and thoughts that undermine our overall happiness.

Letting it all go, however, would mean undoing the habit of a lifetime. ■

The end?

"LET yourself go" now has a whole new meaning, but there are fewer things harder to let go of. Our concept of ourselves as individuals in control of our destinies underpins much of our existence, from how we live our lives to the laws of the land. The way we treat others, too, hinges largely on the assumption that they have a sense of self similar to our own.

So it is a shock to discover that our deeply felt truths are in fact smoke and mirrors of the highest order. What are we – whatever it is we are – to do?

First of all, keep it in perspective. Much of what we take for granted about our inner lives, from visual perception to memories, is little more than an elaborate construct of the mind. The self is just another part of this illusion.

And it seems to serve us well. In that respect, the self is similar to free will, another fundamental feature of the human experience now regarded by many as an illusion. Even as the objective possibility of free will erodes, our subjective experience of it remains unchanged: we continue to feel and act as though we have it.

The same will surely be true about the self. The illusion is so entrenched, and so useful, that it is impossible to shake off. But knowing the truth will help you understand yourself – and those around you – better. **Richard Fisher**

CHAPTER EIGHT

SLEEP

Within a few hours of reading this you will lose consciousness and slip into a strange twilight world. Where does your mind go during that altered state – or more accurately states – we call sleep? And what is so vital about it that we must spend a third of our lives unconscious?

The answers remain elusive, but progress is being made all the time. So let us take a journey into the long, dark night of the mind, starting with its most bizarre aspect: the world of dreams.

In your dreams

A visit to the land of Nod takes your mind on fabulous adventures. What shapes them, asks **David Robson**

MARY SHELLEY'S involved a pale student kneeling beside a corpse that was jerking back to life. Paul McCartney's contained the melody of *Yesterday*, while James Cameron's feverish visions inspired the *Terminator* films. My dreams often feature a shrinking rabbit, which then turns into an insect that leaps across the lawn and under the neighbour's fence.

With their eerie mixture of the familiar and the bizarre, it is easy to look for meaning in these nightly wanderings. Why do our brains take these journeys and why do they contain such outlandish twists and turns? Unfortunately for armchair psychoanalysts, Sigmund Freud's attempts to interpret our dreams remain hotly disputed. Nevertheless, neuroscientists and psychologists have recently made big strides in understanding the way the brain builds our dreams, and the factors that shape their curious stories. Along the way, they have found startling hints that our use of technology may be permanently changing the very nature of this fundamental human experience.

Anyone who has ever awoken feeling amazed by their night's dream only to forget its contents by the time they reach the shower will understand the difficulties of studying such an ephemeral state of mind. Some of the best attempts to catalogue dream features either asked participants to jot them down as soon as they woke up every morning or, better still, invited volunteers to sleep in a lab, where they were awoken and immediately questioned at intervals in the night. Such experiments have shown that our dreams tend to be silent movies – with just half containing traces of sounds. It is even more unusual to enjoy a meal or feel damp grass beneath your feet – taste, smell and touch appearing only very rarely.

Similar studies have tried to pin down some of the factors that might influence what we dream about, though they have struggled to find anything reliable. You might expect your dreams to reveal something about your personality, but traits such as extroversion or creativity do not seem to predict features of someone's journeys through the land ›

MALLORY MORRISON

of Nod. Shelley and McCartney's dreams aren't that unlike ours.

"People's dreams seem to be more similar than different," says Mark Blagrove at Swansea University in the UK. That suggests common symbols in dreams might represent shared anxieties and desires, but attempts to find these have also been disappointing – something like a surreal shrinking rabbit, for instance, probably reveals nothing "that you didn't already know", says Blagrove, gnomically.

A more fruitful approach has been to look at the brain's activity during sleep for clues to the making of our dreams. Of particular interest is the idea that sleep helps to cement our memories for future recall (see page 114). After first recording an event in the hippocampus – which can be thought of as the human memory's printing press – the brain then transfers its contents to the cortex, where it files the recollection for long-term storage.

This has led some psychologists, including Blagrove, to suspect that certain elements of the memory may surface in our dreams as the different pieces of information are passed across the brain. Studying participants' diaries of real-life events and comparing them with their dream records, his team has found that memories enter our dreams in two separate stages. They first float into our consciousness on the night after the event itself, which might reflect the initial recording of the memory, and then they reappear between five and seven days later, which may be a sign of consolidation.

Even so, it is quite rare for a single event to appear in a dream in its entirety – instead, our memories emerge piecemeal. "What usually happens is that small fragments are recombined into the ongoing story of the dream," says Patrick McNamara at Northcentral University in Prescott Valley, Arizona. And the order in which the different elements appear might reflect the way a memory is broken down and then repackaged during consolidation.

One of McNamara's studies, which compared one individual's dream and real-life diaries over a two-month period, found that a sense of place – a recognisable room, for instance – was the first fragment of a memory to burst onto the subject's dreamscape, followed by characters, actions and finally physical objects.

While it may cement a memory into our synapses during consolidation, the sleeping brain also forges links to other parts of your mental autobiography, allowing you to see associations between different events. This might dredge up old memories and plant them in our dreams, which in turn might explain why we often dream of people and places that we haven't seen or visited for months or even years. It could also lie behind those bizarre cases of mistaken identity while dreaming, when objects or people can appear to be one thing, but assume another shape or character – such as the shape-shifting rabbit that haunts my dreams. "It's a by-product of the way the brain blends different elements," says McNamara.

Our dreams are more than a collection of characters and objects, of course. Like films or novels, they tell their stories in many different styles – from a trivial and disordered sequence to an intense poetic vision. Our emotional undercurrents seem to be the guiding force here. Ernest

33%

of dreams contain bizarre elements impossible in everyday life

MALLORY MORRISON/CORBIS

"Dreams tell their stories in many styles – from trivial disordered sequences to intense poetic visions"

MONOCHROME OR TECHNICOLOUR?

Strong hints that technology drives our dreams emerged with puzzling reports in the 1950s that most people dreamed in black and white. Why? Curiously, this seemed to change over the following decade, and by the late 1960s the majority of people in the West seemed to dream in colour again. What could cause the transformation?

Eva Murzyn at the University of Derby, UK, puts it down to changes in broadcasting – TV burst into colour at about the same time as a generation's dreams emerged from greyscale. Intriguingly, she has found that a difference still lingers to this day – those born before the advent of colour TV are still more likely to report dreaming in black and white than those born afterwards.

Hartmann, a psychiatrist at Tufts University in Medford, Massachusetts, has studied the dream diaries of people who have recently suffered a painful personal experience or grief. He found that they are more likely to have particularly vivid dreams that focus on a single central image, rather than a meandering narrative. These dreams are also more memorable than those from other, more placid times.

Why would our emotions drive the form of our dreams in this way? Hartmann suspects this might also reflect underlying memory processes – our emotions, after all, are known to guide which memories we store and later recall. Perhaps the intense images are an indication of what a difficult process it is integrating a traumatic event with the rest of our autobiography. The result may help us to come to terms with that event. "I think it makes a new trauma less traumatic," says Hartmann, though he readily admits that his hypothesis is difficult to prove.

Despite these advances, many, many mysteries remain. Top of the list is the question of the purpose of our dreams: are they essential for preservation of our memories, for instance – or could we manage to store our life's events without them? "There's no consensus," says McNamara. But understand their origins, he says, and we would get a better grasp on consciousness in general.

7 to 9

hours of nightly shut-eye is best for adults

Our dreams tend to be silent movies

Then there's the impact of our lifestyles on our night-time consciousness, with some research suggesting that TV may have caused a major shift in the form and content of our dreams (see "Monochrome or technicolour?", bottom left). If a few hours of television a day can change the nature of our dreams, just imagine what our intense relationships with computers are doing. Eva Murzyn at the University of Derby, UK, for instance, has found that people who take part in the *World of Warcraft* online role-playing game incorporate its user-interface into their midnight adventures.

Awesome nightmares

And, inspired to look into it by her own son's gaming, Jayne Gackenbach at MacEwan University in Edmonton, Canada, has found that players are beginning to report a greater sense of control over their dreams, with the feeling that they are active participants inside a virtual reality. She points out that gamers are more likely to try to fight back when they dream of being pursued by an enemy, for instance. Ironically, this interaction seems to make their dreams less scary and more exciting. "They say things like – 'this was a nightmare, but it was awesome'. They are invigorated by it," Gackenbach says.

If you're after a more peaceful night, you might want to take inspiration from Hervey de Saint-Denys, an early dream researcher in the 19th century who found that certain scents could direct his dreams. To prevent his own expectations from clouding the results, he asked his servant to sprinkle a few drops of perfume on his pillow on random nights as he slept. Sure enough, he found that it led his dreams to events associated with that particular scent. More generally, recent studies confirm that sweet smells can spark emotionally positive dreams.

Then again, if you are like me, you may prefer to let your subconscious direct your nightly wanderings. As unsettling and upsetting as they can sometimes be, it is their mystery that makes dreams so enchanting. ■

The little sleep

Some people would kill for a few more active hours in the day – could new technology deliver them? **Jessa Gamble** investigates

Maybe it's a brutal deadline that has kept you up. Or your newborn, who didn't let you sleep all night. Or perhaps you're just at a club and don't want to cut the night short.

Even those of us who love our shut-eye must admit that there are times when we wish we didn't need so much of it. Now a small group of researchers is starting to zero in on ways to squeeze a full night's sleep into fewer hours, using technology rather than drugs. If they succeed, they could do more than help us cram more activities into our waking hours – they could, in theory, provide an alternative route to the fountain of youth.

While sleep researchers have not yet managed to reach a consensus on why we sleep, they have a pretty good idea of how we do it. During sleep, complex changes occur in the brain. Some of these can be observed with an electroencephalograph, which uses electrodes placed on the skull to track the brain's electrical activity. Your nightly 8 hours are not a single undifferentiated lump, but instead multiple cycles of four stages. We go through these sequentially; during a good night's sleep, we'll repeat each roughly 90-minute cycle five or six times (see diagram, page 112).

5%

of the population can function normally on 4 hours' sleep

Some of the stages have especially strong associations with specific functions. Stage 1 is considered the boundary between sleep and wakefulness. Its length varies from person to person and throughout the night, but it tends to lasts between 5 and 15 minutes, and its primary function appears to be to get us to the deeper stages. "You can think of it as the on-ramp to sleep," says Chris Berka, a neuroscientist at Advanced Brain Monitoring in Carlsbad, California.

The transition to stage 2 is sometimes disrupted by what is known as a hypnic jerk, a falling sensation that results in a violent twitch as the body's muscles begin to relax. That relaxation makes stage 2 sleep ideal for naps. Lasting 20 minutes or so, it restores fatigued muscles and replenishes alertness, and if you are awakened during this stage, you'll feel refreshed.

Not so for stage 3. Its characteristic brainwaves on EEG lend it the name "slow-wave sleep". For reasons that are poorly understood, there is a robust relationship between this stage and certain restorative mechanisms. For example, growth hormones secreted by the pineal gland stimulate the repair of bone and muscle, and prolactin regulates the immune system. It's also the hardest to wake from. If you are roused, say, 45 minutes into sleep, you will feel groggy, confused and irritable. The time we spend in stage 3 varies, but it lasts about 60 minutes in the first cycle of the night, diminishing in duration with each subsequent cycle and increasingly being replaced by an entirely different phase known as rapid-eye-movement (REM) sleep. This is when the majority of dreaming is thought to take place.

To get by on fewer of these nightly cycles, our main strategy has simply been to curtail sleep at predetermined times, courtesy of the cursed alarm clock. Get less sleep than you need, however, and say goodbye to attention, alertness, concentration, judgement and problem-solving (see graph, below right). To reduce these effects, we've traditionally enlisted stimulants like caffeine. It works well enough in the short term, which may explain why 90 per cent of Americans use it. However, caffeine wears off after a few

C.J. BURTON/CORBIS

"No stimulant can stave off the alarming long-term effects of sleep deprivation"

hours and is subject to the law of diminishing returns.

In the late 1990s, a putative wonder drug called modafinil briefly promised to trounce caffeine. But excitement fizzled when it became clear that the restorative effects of a tablet of modafinil were equivalent to no more than a few cups of coffee. While its longer half-life meant it could be taken less frequently, with fewer gastrointestinal effects, the price – coupled with the necessary prescription – meant caffeine stayed king.

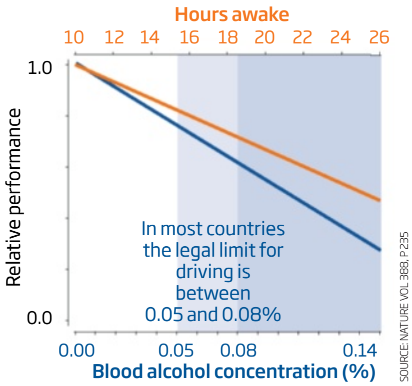
In any case, no stimulant can stave off the far more alarming physical effects of sleep deprivation. In one experiment at the University of Chicago, researchers kept rats awake continuously. Most died after 21 days. Last year, clues to the mechanism were revealed. After keeping volunteers awake for 29 hours, researchers at the University of Surrey, UK, found that their white blood cell counts soared as though they had been injured. "It is a fair conclusion that sleep loss adversely affects one's ability to combat infections," says James Krueger, who studies sleep and immunity at Washington State University in Pullman.

It's not just acute sleep deprivation, however – over time, even the moderate daily shortfall most of us endure during an average working week will get us in trouble. After reviewing 15 studies of 470,000 people over 25 years in eight countries, researchers at the University of Warwick, UK, concluded that "short sleepers" – those consistently getting fewer than 5 hours per night – increased their risk of heart disease, diabetes, stroke and even cancer. No stimulant can fix that.

As we improve our understanding of what happens during the different phases of sleep, however, it may become possible to take a more targeted approach to increasing our waking hours. "Ideally you want 8 hours," says Nancy Wesensten, a psychologist at Walter Reed Army Institute of Research in Silver Spring, Maryland. "The goal is to get the same benefits from 6 hours."

Drunk on fatigue

After about 17 hours awake, your cognitive and motor skills resemble those of someone who is intoxicated



11 days

The longest anyone has stayed awake

Instead of lopping off great, undifferentiated chunks, however, sleep researchers began to investigate how they might carve out the slivers deemed least important, to compress sleep to include just the critical parts. In 2008, hints emerged that these might be the deeper stages. For example, drugs that enhance slow-wave sleep vastly reduced fatigue and other side effects in volunteers, even if they had slept for only 5 hours. Unfortunately, trials on one such drug were halted when it was found to carry a higher incidence of "psychiatric side effects".

Twenty winks

Luckily, there was another option. "Brain stimulation techniques can do the same thing," Wesensten says, "only better."

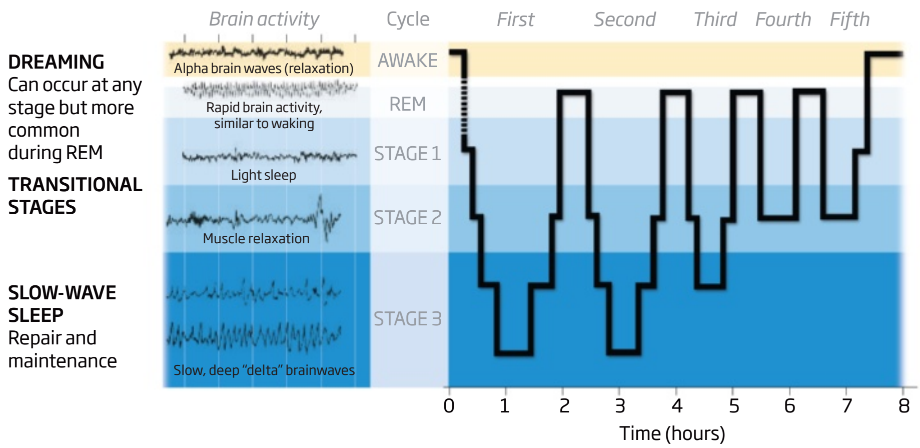
Wesensten has spent her career finding ways to help soldiers face the extremes of what most of us tussle with during an average working week: they must make crucial, split-second decisions despite frequent sleep deprivation. "I'm not interested in whether someone can stay awake for five days in a row," she says. "I want to give them well-rested levels of performance no matter how long they've been awake."

Soldiers must attempt strategic naps in occasional 1 or 2-hour windows whenever the opportunity arises. How do you stay functional – not to mention sharp? There is a way. Dip into stage 2 sleep for as little as 3 minutes, and you can benefit from its refreshing effects.

For many people, though, the anxiety of knowing they must sleep within a precise amount of time would be more effective than a stimulant in keeping ›

Cycling through the land of nod

A good night's sleep of about 8 hours is comprised of five or six cycles. Slow-wave sleep is thought to be the most beneficial



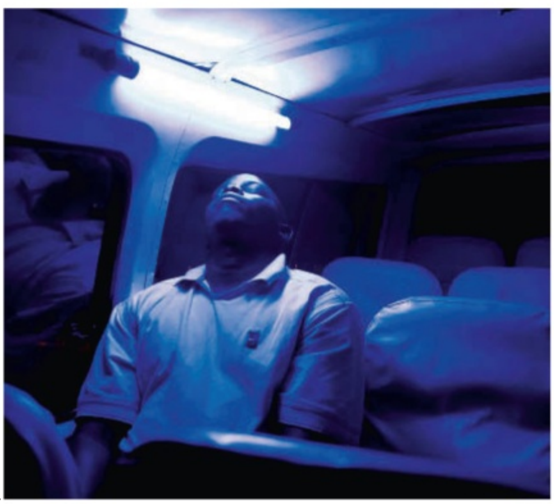
them awake. The US Defense Advanced Research Projects Agency funded Berka to tackle this problem without pharmaceuticals, and such research may benefit us all eventually. Her team designed a device they call the Somneo mask, a thick, padded band that covers the cheeks, ears and much of the head. It carries a heating element around the eyes, piggybacking on research that shows facial warming sends people to sleep. In so doing, the mask fast-tracks the wearer through the stage 1 on-ramp, which seemingly has few inherent benefits, to enter stage 2 more quickly – albeit by only 2 minutes. "This might not sound like much, but it's the same reduction we see with hypnotic drugs," says Berka, such as zolpidem, which is used to treat insomnia.

More importantly, the mask's built-in EEG monitors any changes in sleep stage. Program it to allow you exactly 20 minutes of sleep, and it will start counting only when it detects actual sleep. Don't want to wake up groggy? If you are approaching stage 3 but don't have time for a full sleep cycle, the mask will trip an alarm. Not just any alarm: the mask contains a blue light that gradually brightens, suppressing the sleep hormone melatonin to help you hit the ground running.

EEG monitoring will help make sure you do not wake up at the wrong time, but it cannot manipulate your brainwaves to help you stay asleep or move you into deeper stages. This is where a technique called transcranial direct current stimulation (tDCS) comes in. It involves administering a weak current to a part of the brain called the dorsolateral prefrontal cortex, and can direct brain waves into an alignment that mimics specific features within the sleep cycle.

100,000

Number of annual car crashes in US related to fatigue



JONAS BENDIKSEN / MAGNUM PHOTOS

Researchers at the University of Lübeck in Germany who used tDCS on the brains of sleeping volunteers were able to shift them between adjacent phases of sleep. First, they deepened sleep by increasing slow waves at the cost of short-wave "lighter" sleep. This artificially induced slow-wave sleep appeared identical to normal sleep and, more importantly, reducing short-wave sleep seemed to have no ill effects. Indeed, the tDCS group showed improvement in subsequent memory tests – notably in the kind of memory that is encoded during slow-wave sleep. "There was no other functional difference between the control group's sleep and tDCS subjects," says team member Lisa Marshall.

tDCS can also move your sleep in the opposite direction, Marshall says. In a follow-up study, the team was able to kick sleepers out of slow-wave sleep and into a lighter waveform more characteristic of stage 2.

Berka says a future version of the Somneo mask could include tDCS to address insomnia. However, while tDCS can help intensify or lighten sleep, Marshall notes that it cannot stimulate the brain to bypass stages 1 and 2 altogether. The method certainly cannot – "as yet", she says – put you into slow-wave sleep at the flick of a switch.

But another technique, transcranial magnetic stimulation, or TMS, might do just that. It is strong enough that neuroscientists at the University of Wisconsin-Madison were able to use it to directly trigger deep sleep. As part of an investigation into increasing sleep efficiency, Giulio Tononi and his team fitted 15 volunteers with EEG caps, and, using an electromagnet held over the skull, generated an electrical current. This induced low-frequency pulses in the part of the brain where slow-wave sleep is generated. Every volunteer who was able to fall asleep under these conditions immediately produced slow oscillations characteristic of stage 3 sleep the moment TMS was flicked on.

"Difficulty falling asleep could account for the cognitive decline seen in normal ageing"

C.J. BURTON/CORBIS

TMS therapy won't be arriving in our bedrooms any time soon, though. The equipment is not portable, and the discomfort of lying in the machine prevented some volunteers from falling asleep at all. Still, the experiment showed that in principle, it is possible to move a person directly from sleep onset to stage 3 sleep, raising the intriguing possibility of bypassing stage 1 and 2 sleep altogether. In theory, doing so could nibble at least 20 minutes' sleep off each cycle. Subtract those minutes from the whole without health consequences – a big, untested "if" – and you might be able to squeeze the mental and physical health benefits of 8 hours of sleep into little more than 6.

If it worked, such a device would effectively add a few weeks to the average person's year – quite a startling increase. This is why some researchers think the technology is very likely to be developed in the near future. "It'll take some mavericks to go out there and push the boundaries," says Julian Savulescu, who directs the Oxford Centre for Neuroethics in the UK. "But it'll happen."

31%

of drivers in the US report having fallen asleep at the wheel at some point in their lives

And that's exactly where he sees a problem. Should such technologies prove safe and become widely available, they would represent an alternate route to human longevity. Time that would otherwise be spent sleeping counts toward an extension of your waking lifespan – if you can afford the device, that is. "You come up against the fair innings argument: that we're each allotted our three score years and ten, and then it's time to retire," he says. "But if you live to 80 but have an effective life of 100, your life is much richer."

Therapeutic rest

And while Savulescu is all for human enhancement, he won't be experimenting with his own sleep any time soon. "You always pay for it later," he says. In particular, bypassing stage 2 could prove problematic. While the study of stage 2 sleep has lagged behind work on other sleep stages, Marshall points to research indicating that this stage may be involved in memory consolidation.

Still, cajoling the brain into specific sleep stages may confer more unexpected benefits. Researchers are just beginning to find evidence of complicated connections between sleep and, for example, mental health and ageing. "People with depression have sleep patterns that look nothing like the cycles of healthy sleepers," says Berka. They spend more time in REM and stage 1 sleep during an average night. Use tDCS to nudge them into a healthy pattern, she says, and it might be possible to ameliorate the symptoms.

Then there's ageing. "Sleep deteriorates like everything else does as you age," says Wesensten. "People have more difficulty falling asleep, and that could account for the cognitive decline we see in normal ageing." But is impaired memory in older adults caused by the decline in sleep, or is it the other way around, or something else entirely? No one can definitively answer this question, but early research hints that tDCS applied to older adults during sleep can restore some of that youthful memory retention.

And if finding a way to sleep like a young person, in turn, makes a person think like their younger self? The fountain of youth may have been as close as our bedrooms all along. ■

Wonder of slumber

Why we sleep is one of life's enduring mysteries. **Liam Drew** dives in

WE SPEND about a third of our life doing it. If deprived of it for too long we get physically ill. So it's puzzling that we still don't really know why it is that we sleep.

On the face of it the answer seems obvious: we sleep so that our brains and bodies can rest and recuperate. But why not rest while conscious, so that we can also watch out for threats? And if recuperation means things are being repaired, why can't that take place while we are awake?

Scientists who study how animals eat, learn or mate are unburdened by questions about the purpose of these activities. But for sleep researchers the "why?" is maddeningly mysterious.

Sleep is such a widespread phenomenon that it must be doing something useful. Even fruit flies and nematode worms experience periods of inactivity from which they are less easily roused, suggesting sleep is a requirement of the simplest of animals.

But surveying the animal kingdom reveals no clear correlation between sleep habits and some obvious physiological need. In fact there is bewildering diversity in sleep patterns.

Some bats spend 20 hours a day slumbering, while large grazing mammals tend to sleep for less than 4 hours a day. Horses, for instance, take naps on their feet for a few minutes at a time, totalling only about 3 hours daily. In some dolphins and whales, newborns and their mothers stay awake for the entire month following birth.

All this variation is vexing to those hoping to discover a single, universal function of sleep. "Bodily changes in sleep vary tremendously across species," says Marcos Frank at the University of Pennsylvania in Philadelphia. "But in all animals studied so far, the [brain] is always affected by sleep."

So most sleep researchers now focus on the brain. The most obvious feature of sleep, after all, is that consciousness is either lost, or at least, in some animals, reduced. And lack of sleep leads to cognitive decline, not only in humans, but also rats, fruit flies and pretty much every other species studied.

Much of our slumber is spent in slow-wave sleep (also known as stage 3 or deep sleep – see diagram, page 112), during which there are easily detectable waves of electrical activity across the whole brain, caused by neurons firing in synchrony about once a second. This is interspersed with other phases, including rapid-eye-movement sleep, where brain activity resembles that seen during wakefulness, and transitional stages between the two states.

It is slow-wave sleep that is generally thought to do whatever it is that sleep actually does. As well as appearing to be the most different to the brain's waking activity, the waves are larger at the beginning of sleep, when sleep need is presumably greatest, and then gradually reduce. And if you go without sleep for longer than usual, these slow waves are larger when you do eventually nod off.

> "Some newborn dolphins and their mothers stay awake for the entire month after birth"

Explanations for sleep fall into two broad groups: those related to brain repair or maintenance, and those in which the sleeping brain is thought to perform some unique, active function.

There has been speculation over the maintenance angle for over a century. It was once a fashionable idea that some kind of toxin built up in the brain during our waking hours which, when it reached

a certain level, made sleep irresistible. Such a substance has never been found, but a modern version of the maintenance hypothesis says that during the day we deplete supplies of large molecules essential for the operation of the brain, including proteins, RNA and cholesterol, and that these are replenished during sleep. It has been found in animals that production of such macromolecules increases during slow-wave sleep, although critics point out that the figures show a mere correlation, not that levels of these molecules control sleep.

The "unique function" school of thought also has a long pedigree. Sigmund Freud proposed that the purpose of sleep was wish fulfilment during dreaming, although scientific support for this notion failed to materialise.

There is good evidence, however, for sleep mediating a different kind of brain function – memory consolidation. Memories are not written in stone the instant an event is experienced. Instead, initially labile traces are held as short-term memories, before the most relevant aspects of the experience are transferred to long-term storage.

Action replay

Several kinds of experiment, in animals and people, show that stronger memories form when sleep takes place between learning and recall. Some of the most compelling support for this idea came when electrodes placed into rats' brains showed small clusters of neurons "replaying" patterns of activity during sleep that had first been generated while the rats had been awake and exploring. "Memory representations are reactivated during sleep," says Jan Born of Eberhard-Karls University in Tübingen, Germany.

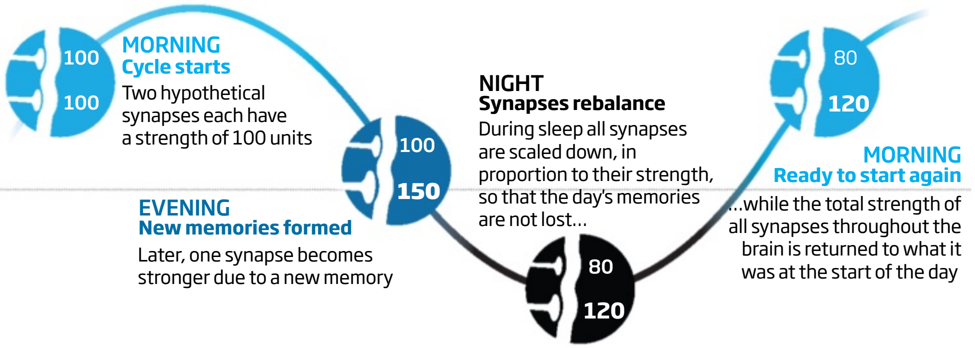
Many labs remain focused on how memory systems are updated during sleep, but since 2003 a new idea has been gaining traction. It straddles both categories of theory, concerned as it is with neuronal maintenance and memory processing.

The hypothesis concerns synapses, the junctions between neurons through which they communicate. We know that when we form new memories, the synapses of the neurons involved become stronger. The idea is that while awake we

MALLORY MORRISON

Memory bank

A new theory about the purpose of sleep says it is to stop our brains being overloaded by the new memories we form each day



are constantly forming new memories and therefore strengthening synapses. But this strengthening cannot go on indefinitely: it would be too expensive in terms of energy, and eventually there would be no way of forming new memories as our synapses would become maxed out.

The proposed solution is slow-wave sleep. In the absence of any appreciable external input, the slow cycles of neuronal firing gradually lower synaptic strength across the board, while maintaining the relative differences in strength between synapses, so that new memories are retained (see diagram, above).

There is now much evidence to support what is known as the "synaptic homeostasis hypothesis". In humans, brain scans show that our grey matter uses more energy at the end of the waking day than at the start. Giulio Tononi and Chiara Cirelli of the University of Wisconsin-Madison, who proposed the hypothesis, have shown that in rodents and fruit flies, synaptic strength increases during wakefulness and falls during sleep. The pair have also shown that when people learn a task that uses a specific part of the brain, that part generates more intense slow waves during subsequent sleep. This kind of downscaling is best done "offline", says Tononi. "You can activate your brain in all kinds of ways, because you don't need to behave or learn."

Synaptic homeostasis has not won over everyone, but it is certainly getting a great deal of attention. It is, says Born, "currently the most influential [theory] among sleep researchers". Frank, however, would like Tononi and Cirelli to provide more detail about mechanisms.

Neither is Jerry Siegel convinced. A neuroscientist at the University of California, Los Angeles, Siegel is sticking with his provocative theory that sleep is simply an adaptive way of saving energy when not doing essential things, such as foraging or breeding, which are in fact more dangerous than napping someplace safe. For Siegel, sleep habits reflect the variety of animal lifestyles, with different species sleeping for different purposes.

It's certainly possible that a phenomenon as complex as sleep performs a multitude of functions, agrees Jim Horne, who studies the impact of sleep loss on health at Loughborough University, UK. And, given the complexity of the human brain, our sleep may well be among the most complicated of all.

Perhaps then it should be no surprise that theories of sleep function are so diverse. Fathoming whether the big "Why?" of sleep will yield a single, succinct solution or require myriad answers is likely to keep biologists up at night for a little while yet. ■

30%

of US workers sleep less than 6 hours a night

NICOLAS DEJESUS

CHAPTER NINE

DEATH

The only certain thing in life is that it will one day end. That knowledge is perhaps the defining feature of the human condition. And, as far as we know, we alone are capable of contemplating the prospect of our demise. That may be a curse, but it also has morbidly fascinating implications: our shifting definition of death, how knowing that we will die gave birth to civilisation, the grim reality of decomposition, and whether it makes sense to fear death. But first, when did we become aware of our own mortality?

PANSY died peacefully one winter's afternoon, her daughter Rosie and her friends Blossom and Chippy by her side. As she lay dying, her companions stroked and comforted her; after she stopped breathing they moved her limbs and examined her mouth to confirm she was dead. Chippy tried twice to revive her by beating on her chest. That night Rosie kept vigil by her mother's side.

Pansy's death, in December 2008, sounds peaceful and relatively routine, but in fact it was highly unusual. Captive chimpanzees are rarely allowed to die at "home"; they are usually whisked away and euthanised. But the keepers at Blair Drummond Safari and Adventure Park in Stirling, UK, decided to let Pansy stay with her loved ones until the last so that their response to her death could be observed.

It is hard not to wonder what was going on in the minds of Rosie, Blossom and Chippy before and after Pansy's death. Is it possible that they felt grief and loss? Did they ponder their own mortality? Until recently these questions would have been considered dangerously anthropomorphic and off limits. But not any more.

The demise of Pansy is one of many recent observations of chimpanzee deaths, both in captivity and the wild, that are leading to surprising insights about our closest living relatives' relationship with death. This, in turn, is opening up another, deeper, question: at what point in human evolution did our ancestors develop a modern understanding of death, including awareness of their own mortality? The answer goes much wider than our attitude to death – it may help us to better understand the origin of our unique way of life.

As far as most animals are concerned, a dead body is just an inanimate object. Some species have evolved elaborate-looking behaviours to dispose of corpses – mole rats, for example, drag them into one of their burrow's latrines and seal it up – but these are practical acts with no deeper purpose or meaning.

Some non-human animals, though, clearly have a more complex relationship with death. Elephants

are known to be fascinated with the bones of dead elephants, while dolphins have been observed spending long periods of time with corpses.

No animal, though, arouses interest as much as chimps do. Psychologists James Anderson and Louise Lock from the University of Stirling, who recorded Pansy's death, point out that her companions' responses were "strikingly reminiscent of human responses to peaceful death", including respect, care, testing for signs of life, attempts to revive, vigil, grief and mourning.

Similar things have been seen in the rare occasions that death has been observed among wild chimps. Primatologists Alexander Piel of the University of California, San Diego, and Fiona Stewart of the University of Cambridge witnessed just such an event in Gombe national park in Tanzania in January 2010. Early one morning, rangers discovered the body of a female chimp, Malaika, who had apparently fallen out of a tree.

When Piel and Stewart arrived at 9.15 am there was a crowd of chimps around Malaika's body. For the next three and a half hours the pair observed and filmed the scene as a succession of chimps visited the body, while others observed from the trees. Some seemed merely curious, sniffing or grooming the body. Others shook, dragged and beat it as if in frustration and anger. Dominant males performed displays of power around it or even with it; the alpha male threw it into a stream bed. Many made distress calls.

"Chimps' response to death is strikingly reminiscent of our own"

When the body was finally removed by rangers, eight of the chimps rushed to where it had lain and intensively – and excitedly – touched and sniffed the ground. They stayed for 40 minutes, making a chorus of hooting calls before moving off. The last chimp to visit the spot was Malaika's daughter Mambo.

What are we to make of this? According to Piel, the chimps' behaviour can be classified into three categories: morbidity, or intense interest in the body, mourning and "social theatre". And as with Pansy's death, these are very reminiscent of how we behave.

"The danger is to anthropomorphise, but much of this behaviour is still practised by modern humans," says Paul Pettitt, an archaeologist at the University of Durham, UK, who studies the origins of human burial. "We see in chimps very simple behaviours that have become elaborated into more formal expressions of mourning. It gives us a feel for what we might expect to have been practised by Miocene apes and early protohumans."

We will never know for sure, of course. But the fossil and archaeological record contains tantalising hints of how this kind of behaviour evolved into modern rituals. And this has become a major question in palaeoanthropology. Our treatment of the dead clearly falls into the category of "symbolic activity", akin to language, art and the other things that make modern humans unique. These were all thought to have emerged around 40,000 years ago, but recent discoveries have tentatively pushed this back to 100,000 years or more.

Anything resembling mortuary practices predating 40,000 years ago used to be dismissed as an artefact.

Last rites: funerals are every bit as symbolic as art and language

GIANNI BERENGO GARDIN/CONTRASTO/EYEVINE

death

But not any more, says Francesco d'Errico of the University of Bordeaux in France. "Most archaeologists now accept that modern humans, Neanderthals and possibly other archaic hominins were engaged in mortuary practices well before 40,000 years ago."

Hominids on a hillside

The earliest signs are very old indeed. In 1975, on a steep grassy hillside near Hadar, Ethiopia, palaeontologists discovered 13 specimens of our 3.2 million-year-old ancestor *Australopithecus afarensis* – nine adults, two juveniles and two infants – all within touching distance of one another and apparently deposited around the same time.

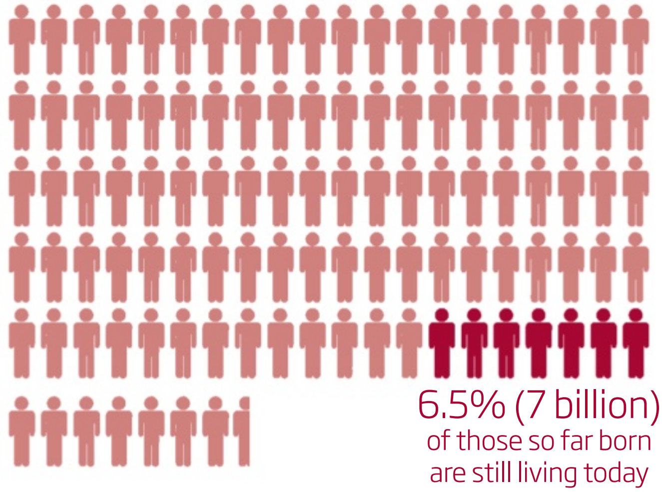
How they got there is a mystery. There is no evidence of a flash flood or similar catastrophe that could have killed all of them at once. There is no sign that the bones had been chewed by predators. They are, as discoverer Donald Johanson later wrote, "just hominids littering a hillside".

Last year, partly in light of chimp research, Pettitt proposed a new explanation: the bodies were left there deliberately in an act of "structured abandonment". That doesn't mean burial, or anything with symbolic or religious meaning. "It was probably just the need to get rid of a rotting corpse," says Pettitt. Even so, it represents a significant cognitive advance over what is seen in chimpanzees, who leave their dead where they fall – perhaps the first stirring of something human. "It could be recognition that the appropriate place for the corpses is not among the living – a first formal division between the living and the dead," says Pettitt.

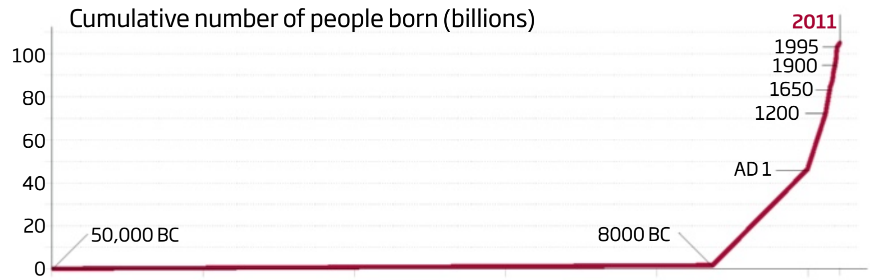
Barring new discoveries it will be impossible to confirm that australopithecines deposited their dead in a special place. But by half a million years ago the evidence is much clearer.

Sima de los Huesos – the pit of bones – was discovered in the 1980s at the bottom of a limestone shaft in a cave in the Atapuerca Mountains of northern Spain. It contained the remains of at least 28 archaic humans, most likely *Homo heidelbergensis*, a probable ancestor of both *Homo sapiens* and Neanderthals.

HOW MANY PEOPLE HAVE EVER BEEN BORN?



107.7 BILLION



You may have heard it said that there are more people alive today than have died in all of human history, but this is not true. According to calculations by demographer Carl Haub, about 107 billion people have been born up until now, and 100 billion of them are dead. You are among the lucky 6.5 per cent of humanity that is still alive. For now, anyway...

SOURCE: HOW MANY PEOPLE HAVE EVER LIVED ON EARTH? BY CARL HOUB 2011/POPULATION REFERENCE BUREAU ESTIMATES

How did they get there? An obvious possibility is that they accidentally fell down the shaft, but that seems unlikely from the way the bones fractured. "It doesn't look like a natural accumulation," says Pettitt. Most of the skeletons are adolescent males or young men, and many show signs of bone disease or deformity.

According to Pettitt, the best explanation is that they were deliberately placed at the top of the shaft after death and then gradually slumped in. If so, this is the earliest evidence of funerary caching, or the designation of a specific place for the dead – perhaps, in this case, for deformed outcasts – a further advancement towards the modern conception of death. Once you have designated places for the dead you are clearly treating them as if they still have some kind of social agency. "Once you've reached that point you're on the road to symbolic activity," says Pettitt.

What did these protohumans understand about death? Did they know that they themselves were mortal? Did they have a concept of an afterlife? "We haven't got a clue," says Pettitt.

What we do know is that funerary caching became increasingly common: bodies are found in places that are ›

hard to account for any other way, tucked into fissures and cracks, in hard-to-reach overhangs or at the back of caves.

From funerary caching it is a short conceptual leap to burial – creating artificial niches and fissures to stash the dead. The earliest evidence we have of this is from two caves in Israel – Skhul and Qafzeh – where the skeletons of 120,000-year-old *Homo sapiens* were found in what are clearly human-made hollows. There is also evidence of Neanderthal burials from around the same time.

All this adds to the evidence that humans were on their way to a symbolic

"Burial was for special occasions; most dead people were cached or abandoned"

culture much earlier than we thought. "Once you start getting deliberate burials, I think it's much more likely that people are thinking in formalised terms, things like life after death," says Pettitt.

Even so, these burials do not represent a point of no return. Only a handful of such sites are known; compared with the number of people who must have died they are incredibly rare. It appears that burial was for special people or special occasions; most dead people were probably still cached or abandoned.

It was not until about 14,000 years ago that most people were buried in what we would recognise as cemeteries. Around the same time people were settling in one place and inventing agriculture and religion – it is probably no coincidence that the world's oldest ceremonial building, Göbekli Tepe in Turkey, was built at that time.

Well before that, however, archaic humans appear to have had a concept of death not unlike ours. Art, language, elaborate funerary practices – they are just expressions of the same thing, says Pettitt. "It's part of what distinguishes us not only from other animals but from every other type of human that's gone before." Graham Lawton ■

Plight of the living dead

Moving and producing brainwaves? You can still be officially deceased, says **Dick Teresi**

IT IS now easier to be declared dead than at any time in human history. The standards have fallen so low that your heart can be beating, your brain can be sending out brainwaves, and the doctor can still declare you an ex-person. The good news: only about 1 per cent of the population is subject to minimal death criteria. The bad news: if you fall into this 1 per cent, you may be vivisected.

But we're getting ahead of our story.

The question "When is a person dead?" has troubled us for thousands of years. It is not a trivial matter, especially to the person about to be buried or cremated. So we look for what we believe to be foolproof clues. Is there a central organ that when it stops functioning means a human is dead? Is there a set of behaviours that signals with certainty that a human has shuffled off this mortal coil, kicked the bucket, expired?

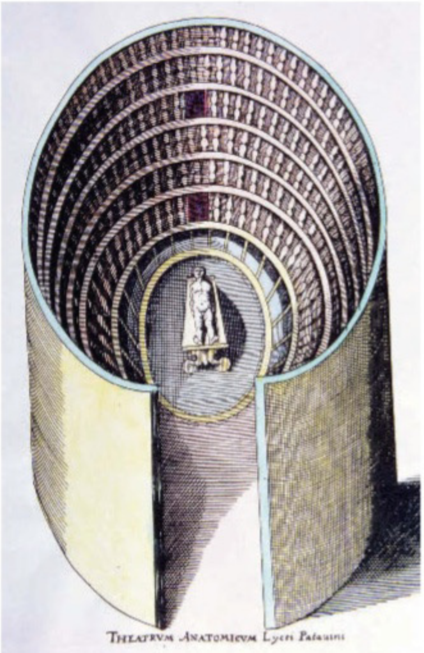
In ancient Egypt the buck stopped at the embalmer. The ancient Greeks knew that many conditions mimicked death. Their test was to cut off a finger before cremation.

Medieval Europeans became increasingly uncertain about who was dead and who was alive as the literature began to fill with accounts of premature burial. The difficulties were underscored by the anatomy theatres that sprang up across Europe in the 1500s to the 1700s, where anatomists would perform public dissections on executed prisoners. The performances sometimes demonstrated that the stars of the show were not quite dead. An anatomist might extract a heart, hold it aloft, and be greeted with gasps because it was still beating. One anatomist, Niccolò Massa, asked to be left unburied for two days "to avoid any mistake".

The 18th century saw the beginning of two important trends. First was the medicalisation of death. Doctors began to appear at the bedside of the dying to administer opiates, and as the boundary between death and life became more confused, medical technologies were introduced to tell the difference. During the next two centuries, innovations were developed that revealed signs of life in those previously thought to be deceased: artificial respiration, smelling salts, electric shocks, the stethoscope, microphones to amplify chest sounds, radiographic fluoroscopy to detect the motion of vital organs, and the ophthalmoscope to examine the circulation of blood in the retina.

The second important trend in this

ANZENBERGER/EYEVINE



BIBLIOTECA NAZIONALE CENTRALE, ROME, ITALY/ROGER-VIOLLET, PARIS/BRIDGEMAN

Show time: public dissections held medieval audiences in thrall

era was a shift from what today we would call cardiopulmonary death towards brain death. There was no such term as "brain death" then, but doctors talked about "sensation" and "will" as the measure of a human.

The concept of brain death played a major role in one of the most extraordinary medical advances of the 20th century. In 1954, surgeon Joseph Murray performed the first successful solid organ transplant, transferring a kidney between living identical twin brothers. It was not long before organs were being transplanted from dead donors into living ones.

This remarkable technology promised to save lives, but it faced a major problem: stale organs. You can use live donors for kidney transplants because people have two kidneys and can lope along on one. But for other organs, you need a dead donor. When a person dies, however, organs are deprived of oxygen.

In 1968, a team of 13 men formed the Ad Hoc Committee of the Harvard Medical School to Examine the Definition of Brain Death, and devised a clever plan to solve the problem. Why not declare dead some of the patients on ventilators in intensive care units, and harvest their organs? These patients were in a deep coma but not dead. Their hearts were still beating. If the ventilator was kept in place even after they were declared dead, their organs would continue to be bathed in blood right up to the moment the surgeons needed them. Voila.

That's precisely what the Harvard committee did. It defined a second form of death, what one doctor calls "pretty dead." Up to that point, doctors had used the cardiopulmonary standard: when your heart stopped beating and you stopped breathing, you were dead. Now there was "death lite", created for the benefit of the transplant industry.

The original Harvard criteria, published in the *Journal of the American Medical Association*, were frighteningly simple, requiring a test shorter than an eye exam. The patient must simply be "unreceptive", showing "no movements" and "no reflexes". Rudimentary clinical tests determined this, such as ice water in the ears, a flashlight in the eyes, cotton swabs touched to the eyeball or reflex tests.

Then comes an "apnea test". The ventilator is disconnected and the doctors see whether the patient can breathe unaided. If not, he is brain dead. Here's the scary part. Then the ventilator is *reconnected*. People talk about "pulling the plug", but the opposite happens. Few people realise this. Nor do they realise that their "do not resuscitate" orders or living wills no longer have legal sway. Once declared brain-dead, you are legally dead and your legal rights go down the drain.

The Harvard criteria ran into trouble almost immediately. The committee did no patient studies, and cited none. In the early 1970s, two studies on actual patients showed that the brains of "brain-dead" people were not always dead. The Harvard tests only indicate whether the brain stem is dead, not the neocortex, the part of the brain where consciousness is most likely seated.

The Harvard criteria did, however, specify a test to make sure this part of the brain was also non-functioning: an EEG. What patient studies showed was that some of these otherwise brain-dead people were producing brainwaves on ›

the EEG. If the brain was dead, what was waving? This problem was easily solved: doctors were told to skip the EEG.

Then in 1981 came the US Uniform Determination of Death Act. It declared that brain death was legal death. The act stated that the "entire brain" must be dead, but left exam techniques to the doctors, who rarely test the cortex.

Even these low standards proved not low enough. Doctors noticed that some brain-dead organ donors ("beating-heart cadavers" in the parlance) were moving about slightly, and exhibiting reflexes. They were violating two of the Harvard criteria: no movement and no reflexes. In the US, this was easily solved by changing the standards. In 1995, the American Academy of Neurologists stated that you could move about somewhat and display reflexes and still qualify as brain-dead.

In 2000, *The Lancet* published a study of 38 brain-dead patients, 15 of whom were still moving in the first 24 hours after being declared dead. Another

"Doctors noticed that beating-heart cadavers were moving about and exhibiting reflexes"

study of 144 beating-heart cadavers found that 79 had retained their reflexes after death. One doctor advises hospitals not to let the families of brain-dead donors see their loved ones after death is declared for fear they'll see these movements.

Through more than 4000 years of history, we have learned that human life is tenacious, and many signs of death are misleading. Yet today, we dissect for their organs patients who in any era before 1968 would be considered very much alive.

Keep in mind, though, that only about 1 per cent of the population is declared dead based on brain-death criteria. And if you are not an organ donor, it won't matter. The ventilator will not be reconnected, and you will be allowed to die a normal cardiopulmonary death, because morticians will not embalm or bury a brain-dead body. They are not idiots. ■

The quest for immortality

We can't achieve it by not dying, so we have to do it some other way, says Stephen Cave

DEATH gets a bad press. Invariably the unwelcome visitor, arriving too soon, he is feared and loathed: "the last enemy" in the words of the Bible.

But a few poets and philosophers throughout history have argued that without death we would be at a loss. It's the prospect of his coming that gets us out of bed in the morning and drives us to great deeds. Now a growing body of evidence from social psychology suggests that these thinkers are right. People might dream of a deathless civilisation, but without death, there would barely be a civilisation at all.

The story begins with the awareness of our mortality. Like all living things, we struggle to survive. Yet unlike other creatures – as far as we know, anyway – we live with the knowledge that this is a struggle we are bound to lose. Our mighty brains, so good at inferring and deducing, tell us that the worst thing that can possibly happen surely will, one day. We must each live in the shadow of our own apocalypse.

That isn't easy. Indeed, it is terrifying and potentially paralysing. So we work very hard to stave off death, to defy it for as long as possible or deny it altogether. All this frantic defiance and denial result in some of our greatest achievements.

This is perhaps most obvious when considering humanity's material progress: agriculture, for example, was invented to give us the food we need to live. Clothes and buildings keep us warm and give us shelter, weapons allow us to hunt and defend ourselves, and medicine heals our sicknesses. The great majority of the material innovations that make up our civilisation are in essence life-extension technologies that we have been driven to invent by the spectre of oblivion.

Of all these achievements, perhaps the greatest is science. This, too, has always been motivated by the fear of death. Francis Bacon, the father of empiricism, described indefinite life extension as "the most noble goal". He sacrificed his own life to the cause, dying of pneumonia contracted while attempting an experiment in cryopreservation involving a chicken and some snow. Science is the business of self-aware mortals – the gods would have no need of biochemistry.

Despite the best efforts of science and technology and the very real improvements in life expectancy that they have achieved, the terrifying prospect of death still hangs over us. That is why humans invented culture as well as material civilisation. Many thinkers, from Georg Hegel to Martin Heidegger, have suggested that its purpose is to reassure us that even though the body will fail, we will still live on. One scholar in this tradition was the anthropologist Ernest Becker, whose 1973 book *The Denial of Death* won the Pulitzer prize. It was this work that inspired a group of social psychologists to seek empirical evidence to support the speculations of the philosophers.

Clinging on

These researchers – Jeff Greenberg at the University of Arizona, Sheldon Solomon of Skidmore College in New York state and Tom Pyszczynski at the University of Colorado – came up with what they called terror management theory: the idea that most of what we do and most of what we believe is motivated by the fear of death. They surmised that if our world views exist to help us cope with mortality, then when reminded of our inevitable demise, we should cling all

death

LAURA THOMAS/MILLENNIUM IMAGES

DE AGOSTINI PICTURE LIBRARY/BRIDGEMAN

"Science is the business of self-aware mortals; the gods have no need of biochemistry"

the more fervently to these beliefs.

One of their starting points was religion, a set of belief systems that arguably epitomise our attempts to assuage the fear of finitude. If religions really are offering existential solace, Greenberg, Solomon and Pyszczynski's thinking went, then when death looms, there should be a measurable increase in religiosity.

Which is just what they found. In one study they asked a group of Christian students to assess the personalities of two people. In all relevant respects the two were very similar – except one was Christian and the other Jewish. The students in the control group judged the two people equally favourably. But those students who were first asked to fill in a personality test that included questions about their attitude to death, and were thus subtly reminded of their mortality, were much more positive about their fellow Christian and more negative about the Jewish person.

This effect is not limited to religion: in over 400 studies, psychologists have shown that almost all aspects of our various world views are motivated by our attempt to come to terms with death. Nationalism, for example, allows us to believe we can live on as part of a greater whole. Sure enough, Greenberg and colleagues found that US students were much more critical of an anti-American writer after being reminded of their mortality. A further study, led by Pyszczynski, showed that students prompted to think about death were not merely disapproving of those who challenged their world views, but willing to do violence to them in the form of giving them excessively large amounts of hot sauce.

These initial studies supported Becker's bleak view that the denial of death is the route of all evil. It causes the creation of in-groups and out-groups, fosters prejudice and aggression, and stokes up support for wars and terrorism. For example, people who were exposed to TV images of planes flying into New York skyscrapers were more likely to support the invasion of Iraq. Terror management theorists initially focused on this dark side. But lately they have come to recognise the positives in our struggle with death.

For example, one of the most powerful forces shaping human culture is the desire to leave a legacy. Some of the greatest achievements of civilisation can be attributed to this ›

urge, from the pyramids of Egypt to John Milton's *Paradise Lost*.

Now terror management theorists have demonstrated that, at least among undergraduates in the US, thoughts of death continue to stoke our drive to be remembered.

Socrates saw this more than 2000 years ago, arguing that much of what men do can be understood as a desperate attempt to immortalise

"The more we actively contemplate death, the more we reject selfish goals such as wealth"

themselves; women, he thought, could take the more direct route of having children. Several studies suggest he was right to see founding a family as a terror management strategy. One showed that German volunteers expressed a greater desire to have children when reminded of death; another that Chinese participants were more likely to oppose their country's one-child policy when similarly primed.

A recent review paper by Kenneth Vail at the University of Missouri in Columbia and colleagues catalogues the many ways that contemplating mortality can be good for us. For example, it can induce us to live more healthily by exercising more or smoking less.

The team also identify an important distinction between conscious and non-conscious death reminders. The latter – subtle or subliminal prompts – tend to cause us to cling unthinkingly to the values of our community. This can be positive if those values are positive, but can also be negative if they induce us to aggressively defend those values against others.

Conscious death reminders, on the other hand, stimulate a more considered response, leading people to re-evaluate what really matters. The more we actively contemplate mortality, the more we reject socially imposed goals such as wealth or fame and focus instead on personal growth or the cultivation of positive relationships.

Which suggests we do not yet think about death enough. ■

Earthly remains

The human body's final journey might not be pretty, but at least it is eventful, says Caroline Williams

IT'S NOT a nice thing to contemplate. But set aside the thought of any of the below befalling you or your loved ones, and what happens to our mortal remains when we are no longer using them is pretty fascinating. If nothing else, it proves that nature is ruthlessly efficient at clearing up its messes.

At least it can be. Very few people in the modern world get to be dead the old-fashioned way – out in the open, exposed to the elements. Of those that do, the speed at which the body turns to dust depends on a mix of factors including temperature, moisture and the animals, insects and microbes that happen to be there. In a relatively warm and moist spot with plenty of insects and

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SUSAN MEISELAS/MAGNUM

Grave story: left in the open, our bodies would turn to dust in just months

scavengers, a human body can be turned to bones within a few weeks and disappear completely in months.

But what about the majority of bodies, which get refrigerated soon after death, then embalmed and put in a coffin? Again, it depends. Temperature and moisture are still the most important factors, but numerous others play a part, from how well the body was embalmed to the tightness of the seal on the coffin, the acidity of the soil and that of the groundwater which will eventually seep inside. All of this means that it is impossible to predict how long a particular body's final journey might take – it can be anything from months to decades.

What we can say, though, is that whatever the timescale, the vast majority of bodies will go through the same sequence of decomposition.

First comes the "fresh" stage. Within minutes of death, carbon dioxide starts to accumulate in the blood, making it more acidic. This causes cells to burst open and spill enzymes which start to digest tissues from within.

The first visible sign of decomposition comes after half an hour or so, as gravity causes the no-longer circulating blood to pool in the parts of the body closest to the ground. At first this looks like purplish-red blotches; over the next day or so it turns into an almost continuous purplish mark known as livor mortis. The rest of the body turns deathly pale.

Around the same time, muscles go floppy and then stiffen as rigor mortis sets in. In life, pumps in the membranes of muscle cells control the amount of calcium ions in the cell – high levels stimulate contraction and low levels allow relaxation. The pumps no longer work after death, so calcium ions diffuse into the cells from the higher concentration outside, causing the muscles to contract.

Rigor mortis passes after two to three days. But what looks like relaxation is actually rot setting in, as enzymes break down the proteins that held the muscles in their contracted state.

Embalming the body stops the rot in its tracks, at least temporarily. Unlike ancient Egyptian embalmers, who aimed to keep the body intact for all eternity, modern embalming is designed to make a corpse look presentable and keep it in one piece long enough to organise a funeral.

This is done by disinfecting the body and replacing the blood and other fluids with a mixture of water, dye and preservatives, usually including formaldehyde. The dye is included to restore something resembling a healthy skin tone, while the formaldehyde preserves the body in several ways, first by repelling insects and killing bacteria. It also inactivates the body's enzymes and makes the tissues more resistant to decomposition by adding cross links to the chains of amino acids that make up proteins.

This protective effect only lasts so long, though, leaving the body more or less back where it started.

The next stage, putrefaction, gets a little ugly – not to mention smelly – as the enzymes, aided and abetted by microbes, get to work.

After 48 hours or so, when enough nutrient-rich fluid has spilled from the burst cells, these microbes spread rapidly. The main beneficiaries are among the 100 trillion bacteria that spent their lives living in harmony with the deceased in their gut. As they break down proteins they churn out two compounds that sound as stinky as they smell, putrescine and cadaverine, and these give a corpse its repulsive odour.

From the outside, putrefaction can be seen as a green hue, slowly

"Very few people in the modern world get to be dead in the old-fashioned way"

spreading from the front of the belly across the chest and down the body. The green colour comes from the action of anaerobic bacteria, which convert haemoglobin in the blood to sulfhaemoglobin.

All this bacterial action also creates gases, including hydrogen, carbon dioxide, methane, ammonia, sulphur dioxide and hydrogen sulphide. These contribute to the stink and also distort the body, blowing it up like a balloon and eventually, after a month or so, bursting it open. Hydrogen sulphide also combines with the iron in haemoglobin to make the black-coloured iron sulphide, which turns the skin darker.

This heralds the start of the third stage: active decay. The rate of decomposition now speeds up and what is left of the flesh is rapidly consumed, until all that remains is the skeleton.

Sometimes, though, something else can happen. If the body happens to be in particularly cold soil, a waxy covering called adipocere, or grave wax, might form. Adipocere is a particularly ›

spooky side effect of the work of some anaerobic bacteria, such as *Clostridium perfringens*, as they digest body fat. It takes around a month to start forming and can leave the corpse with what looks like a wax coating.

The final stage – breakdown of the skeleton – takes the longest. For the bones to disappear the hard mineral parts need to be broken down. This happens if they come into contact with acidic soil or water, and speeds up if they are mechanically broken up by tree roots or animals. Once the hard stuff is gone, the body's last proteins, including the collagen that once gave the bones flexibility, succumb to bacteria and fungi and disappear. And that is the end of your physical existence.

There are, however, some cases where this sequence of events doesn't play out at all and the body doesn't get a chance to decay. If the corpse is kept completely dry, bacteria can't do their work and the tissues will mummify. The same goes for bodies that fall into natural preservatives such as bogs, salt marshes or snow, where bacteria don't thrive and the body's enzymes don't work.

"In rare cases a body can be stripped to the bone and chewed into tiny pieces in days"

Then there are the rare cases when a person dies in the company of hungry scavengers. In these cases the body can be stripped to the bones and chewed into tiny pieces in a matter of days. The same can happen under the sea.

Of course, without a bog, dog, shark or icy grave to hand, the only realistic way to avoid the harsh realities of decay is cremation.

In a chamber heated to 750 °C, the coffin and entire corpse can be almost completely burned in under 3 hours. After that, the ashes are passed through a grinder called a cremulator to take care of any particularly big or stubborn bones that haven't disintegrated and turn the entire remains into fine ash.

And that, as they say, is that. It may not be pretty, but it's one of the few definites in life: ashes to ashes, dust to dust, in the end there's not a lot left. ■

Don't fear the reaper

Most of us do, but it doesn't make sense, says philosopher Shelly Kagan

ONE of the commonest reactions to death is fear. Indeed, "fear" may be too weak a term: terror is more like it. But is fear of death a rationally appropriate response?

The crucial word here is "appropriate". I don't want to deny that many people are afraid of death. What I want to know is whether fear of death is an appropriate response.

Under what conditions does it make sense to feel fear? Three requirements come to mind. The first is that the thing you are afraid of has to be bad. I imagine that this is fairly uncontroversial.

The second is that there has to be a non-negligible chance of the bad thing happening. It is not enough that it's a logical possibility. There is, for example, a chance that you will be ripped to pieces by tigers, but it's negligibly small. If you were to tell me that you are afraid that you will die this way, then I would say that such a fear is not appropriate.

Condition number three is more controversial: you need to have some uncertainty about whether the bad thing will actually happen, or else how bad it will be. To see the point of this condition, we need to imagine a case where a bad thing is certain to happen, and you know how bad it is going to be. In circumstances like that, fear is not an appropriate response, even though the first two conditions have been met.

Suppose that every day you come to the office with a packed lunch. For dessert you bring a cookie, and every day somebody steals it – admittedly not the worst thing in the world, but it's a bad thing. Furthermore, there is a more than negligible chance that your cookie will be stolen tomorrow. So the first two conditions are in place.

But not the third. It is pretty much guaranteed that your cookie will be stolen tomorrow. The bad thing is certain to happen, and you know how bad it is. In this case, I think, fear doesn't make any sense. In contrast, if the thief strikes at random, then you might reasonably be afraid.

One other point is worth mentioning. Even when fear makes sense, there's a proportionality condition that should be kept in mind. Even if some fear is appropriate, the amount of it might still be inappropriate. When the risk is slight, mild concern may be all that is appropriate. Similarly, the amount of fear needs to be proportional to the size of the bad.

Armed with these ideas, it might seem that we are now in a position to

HIROJI KUBOTA/MAGNUM

ask whether fear of death is appropriate. However, we first need to clarify something important: what exactly are we afraid of? There are different ways to answer this question, and depending on which we have in mind, fear may, or may not, be appropriate.

One thing you might worry about is the process of dying. Insofar as there is some chance that you will die a painful death, there seems to be room for some fear. But I imagine this is not what most people have in mind. What most people mean is that they're afraid of death itself – afraid of what it will be like to be dead. In this case, I think, the conditions for appropriate fear are not satisfied. The main point here is that there is nothing that being dead is like. It involves no kind of experience at all, so it is not intrinsically bad. Thus the first condition for appropriate fear isn't satisfied. (Things might look different if you believe in an afterlife.)


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Of course, I am not suggesting that there is nothing bad about death. On the contrary, I accept the "deprivation" account, according to which death is bad by virtue of the fact that you are deprived of the good that you would have if you weren't dead.

So perhaps we can specify an appropriate object of fear this way. Instead of fearing what death will be like, perhaps we should fear the deprivation of life. If so, perhaps fear of death is appropriate after all.

But that's not quite right either. First

"I am not suggesting there is nothing bad about death; on the contrary"

of all, I believe that immortality would not be good for us; to be condemned to live forever would be a punishment, not a blessing. So fear is not appropriate. More precisely, if what we are afraid of is the inevitable loss of life, then the object of our fear is not bad, but good, and so fear is still out of place.

However, even if immortality would not be bad, it doesn't follow that fear of death is appropriate. Appropriate fear requires a lack of certainty with regard to the coming of the object of our fear. And I know that I am going to die.

But now a different possibility suggests itself. Fear of death is inappropriate because death is certain. But what is not at all certain is when you are going to die. Perhaps, then, what we should be afraid of is not loss of life per se, but rather the possibility that we will die sooner rather than later.

Consider an analogy. Suppose you're at a party. It's great, and you wish you could stay, but this is taking place in high school, and your mother is going to call and tell you it's time to go home. Now, there's nothing bad about being at home; it's intrinsically neutral. You just wish you could stay at the party.

Suppose you know that the call is going to come at midnight, guaranteed. Then, I think, there isn't anything to be afraid of. But if all you know is that your mother is going to call some time between 11 pm and 1 am, the conditions for appropriate fear have been met. There is something bad, there is a non-negligible chance of it happening, and yet there is also a lack of certainty that it will happen. Now some degree of fear makes sense. Perhaps we have something similar with regard to death. Perhaps it makes sense to be afraid given the unpredictability of death.

Further distinctions might be helpful. Am I afraid that I will die soon, in the sense that, given the range of years I might reasonably hope for, death may come sooner rather than later? Or am I afraid that I will die young, with death coming sooner for me than it does for others? These ways of specifying the object of my potential fear differ in important ways, including how much fear is appropriate, and when.

Take the fear of dying young. Clearly, if you have reached middle age, any fear of dying young is irrational. But even among the young, the chance of this actually happening is extremely small.

As one grows older, the chance of dying within a given period increases. But even here, fear that one will die soon can easily be out of proportion. Even an 80-year-old has a more than 90 per cent chance of living at least another year.

Obviously, fear that death may come soon can make sense among the very sick or the very aged. But for the rest of us, I think, it is typically misplaced. If you are reasonably healthy and yet you say to me, "I am terrified of death", then all I can say in response is that I believe you, but terror is not appropriate. It doesn't make sense, given the facts. ■